STUDIES ON THE CROWN RUST OF OATS CAUSED BY PUCCINIA CORONATA CDA. VAR. AVENAE FRASER AND LED.

A Thesis

Submitted to the Aligarh Muslim University, Aligarh

for the Degree of Doctor of Philosophy

in Botany (Plant Pathology)

By

Syed Tauseef Ahmad

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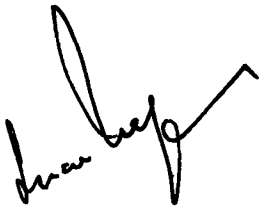
CERTIFICATE

This to certify that the thesis entitled " Studies in the crown rust of oats caused by Puccinia coronata Cda. var. avenae Fraser and Led." submitted for the award of the Degree of Doctor of Philosophy in Plant Pathology (Botany), Faculty of Science, Aligarh Muslim University, Aligarh, is a faithful record of the bonafide research work carried out by Mr. Syed Tauseef Ahmad, under our guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.



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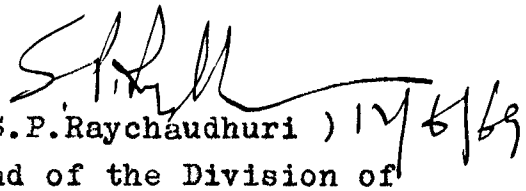

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INTRODUCTION

Agricultural sector contributes more than 50 per cent of India's national income and is the means of livelihood of about 70 per cent of its population. Although, cultivators are intelligent and keen to grow more food; they are in most cases ignorant of the remedial measures for combating the disease caused by micro organism.

In amongst the cereals, oat (*Avena sativa* L.)is one of the most important small grain crop of the world. It occupies an extensive acerage in different countries and ranks third in the U.S.A., while in India about 200,000 acres is under its cultivation. This crop is subjected to innumerous disease hazards, Dickson (1956), however, the crown rust and stem rust caused by *Puccinia coronata* Corda var.*avenae* Fraser and Led. and *P.graminis avenae* Erikss. and Henn., respectively, constitute the most important diseases. The epidemics caused by them are also not uncommon, Pammel (1907).

In India, Barclay (1889,1891) for the first time reported the existance of crown rust on grasses. It was subsequently reported by Butler in 1909 (Butler and Bisby, 1931) from Bihar, Padwick and Khan (1944), Roy (1946), and Payak and Misra (1963) from West Bengal, and Misra, Sharma, Joshi and Singh (1964) from Uttar Pradesh. Mehta (1940), while surveying the oat rusts situation in India reported that the stem rust and crown rust differ in their distribution, the former is confined to the "Southern region" specially in the Nilgiris, and the latter in the "Northern region".

The uredial and telial stages of the rust have been reported to occur besides its main host (*Avena sativa*)on *Agropyron* sp., *Agrostis hookeriana* Kunw., *Brachypodium sylvaticum* Beauv.,*Festuca gigantia* Vill., *Helictotrichon virens* (Nees) Henr., *Piptatherum holciforme* Roem. and Schult., *Poa flexuosa* Sm. and *Stipa* sp. pycnial and aecial stages occur on *Eleagnus umbellata* Thumb., *Berchemia lineata* DC., *Rhamnus dahurica* Pall., *R.pontapomica* Parker, *R.procumbens* Edgw., and *R.virgatus* Roxb., Barclay (1889,1891),

Arthur and Cummins (1933), Padwick and Khan (1944) and T.S. and K.Ramakrishnan (1946).

The conclusion with regard to germination of teliospores of cereal rusts had been contradictory. In some cases the dormancy of cereal rusts teliospores was shortened by alternate periods of freezing and thawing and also by wetting and drying, Kains (1916), Maneval (1922,1927), Johnson (1931), Johnson and Newton (1933), Prasada (1948), Brown and Johnson (1949). In case of crown rust of oats, Zimmer et al. (1961) failed to break the dormancy by physical or chemical means and concluded that naturally overwintered teliospores germinated readily as against those produced under artificial conditions and thus supported the earlier report of Hoerner (1921,1922).

Prior to the classic work on physiologic specialisation by Eriksson and Henning (1894), Klebhan (1892) divided crown rust into two species, P.coronata (Corda) Kleb. and P.coronifera Kleb. based upon their ability or failure to infect R.frangula L. and R.cathartica L., respectively. This was questioned by Wehlue,Dietz and Mitley (1922), Dietz (1926), Fraser and Ledingham (1933), Murphy (1935), Straib (1937) and Brown (1938). They were, however, considered as formae speciales. Following Stakman's work (1936) on stem rust of wheat, the formae speciales have been given the rank of varieties. Out of 17 varieties of the crown reported from different part of the world, only 4 varieties viz. P.coronata avenae, P.coronata himalensis Payak and Misra (1963), P.coronata agrostis and P.coronata festucae Ahmad,Misra and Singh (1968)have been reported from India.

In the U.S.A., Hoerner (1919) established the presence of 4 races within the variety avenae of P.coronata on the basis of infection types developed on two oat varieties. Popp (1926) and Parson (1927) however, differentiated 5 races on 4 oat varieties. In Germany, Frenzel (1930) and Straib (1937) identified 35 and 142 races respectively, the former used 9 differentials while the latter 15 differentials. Murphy (1930) using 33 oat varieties as possible differentials identified races (forms) 1-9. Murphy (1935) selected 13 oat varieties as standard differentials and identified races 1-55. Stakman,Levine,Christensen and Isenbeck (1935) added races 54 to 57; Peturson from Canada (1935) races

36 and 39; Waterhouse from Australia (1935) race 40 (Simons and Murphy, 1955); Murphy and Levine from the U.S.A. (1936) race 41 and Brown from England (1937) races 42 to 44 on the same differentials. Races 45 to 113 were later on reported from different parts of the world on the basis of the reactions on these differentials, Moore, Downie and Murphy (1936), Kingsolver and Murphy (1940), Vallega (1942), Rosen and Murphy (1951), Waterhouse (1952) and Silva (1953). Recently Simons and Murphy (1955) found out a better set of differentials comprising of 10 oat varieties which facilitates the differentiation of many new races.

Like other cereal rusts, the control of oat rust by chemicals is neither practical nor economically feasible, although there have been number of attempts to control the rusts by chemicals in recent years, Mc Callan (1956), Hasket and Johnson (1956), Dickson (1959), George (1964), Hobbs and Futtrel (1966) and Simons and Michel (1967). The use of resistant varieties appears to be the only satisfactory method for the control of crown rust, specially in a country like India. Several attempts have been made to breed oat varieties resistant to crown rust from time to time, Murphy, Stanton and Stevens (1937), Goetsch (1942), Coch et al.(1945), Litzenberger (1949), Ogle and Hayes (1953), Finkner (1954), Simons (1956) and Simons, Sadanaga and Murphy (1959).

In recent years, more acreage has been brought under cultivation of oats as a result of the development of food processing industries in India. There is paucity of information about the various aspects of this rust; therefore, it was considered desirable to study the following:-

Effect of plant extracts on the germination of uredospores.

Effect of exposure to Ultraviolet and Infra red rays on the germination of uredospores,

Factors influencing the formation and germination of teliospores,

Studies on host range,

Assessment of losses,
Physiologic specialisation,
Irradiation to Ultra violet and Infra red rays in relation to pathogenicity,
Chemical mutagenesis in oats,
Sources of resistance in oats, and
Studies on the control of the rust:-
(a) cross protection;
(b) protection by cross inoculation;
(c) by fungicides; and
(d) breeding for resistant varieties.

MATERIAL AND METHODS

The inoculum of race 227 of *P.coronata avenae* raised through single spore on oat variety Victory was used throughout the studies unless stated otherwise.

Effect of Plant Extract on the germination of uredospores

For determining the effect of plant extract on the germination of uredospores of crown rust, some wild and cultivated plants of Simla viz. *Thalictrum javanicum* Blume, *T.reniforme* Royle, *Cannabis sativa* L., *Chenopodium album* L., *Datura stramonium* L., *Eucalyptus* sp., *Oxalis corniculata* L., *O.ocetocella* L., *Rumex nepalensis* Sprange, *R.hastatus* Don, *Puraria* sp., *Urtica dioica* L., *U.parviflora* Roxb., *Girardinia heterophylla* Decne, *Geranium* sp., *G.lucidum* L., *G.divaricatum* Ehrh. & Beitr., *G.nepalense* Sweet, *Impatience balsamina* L., *Rhamnus virgatus* Roxb., *R.purpureus* Edgw., *Viola canescens* Wall., *Vitis himalayana* Brandis, *V.parviflora* Roxb., *Papaver* sp., *Berberis aristata* DC., and *B.lycium* Royle were selected and leaf extract wer prepared by crushing 50 g of washed leaves in pestle and mortar to which 10 ml of water was added. The extract was filtered. This has been named as (S) or standard extract. A few drops from plants extracts were transferred to clean slide. Later the uredospores were transferred to such a solution and was kept in an incubation chamber (Riker and Riker, 1936). Every effort was made that the number of uredospores in each case was equal. The uredospores that germinated and that failed to germinate were counted. Whenever the effcet of concentration other than the above was determined, the extracts were diluted by adding more water. Uredospores that germinated in water served as control. The pH and other contents of the leaf extract by paper chromatography were also determined as and when required. For each treatment there were three replicates.

Effect of Ultra violet and Infra red rays on the germination of uredospores

Dried uredospores were transferred to small card pieces. The cards having uredospores were exposed to 15 W. Ultra violet (UV) radiation at 9 inches distance for 10, 20, 30, 40, 50, 60,

70, 80, 90, 100, 110 and 120 minutes.

Similarly uredospores were also exposed to 250 W. Infra red (IR) radiation for 1, 5, 10 and 15 minutes. The treated and untreated uredospores were tested for germination in distilled water as on page 5. Dried uredospores but not exposed to UV or IR served as control.

Factors Influencing the Formation and Germination of Teliospores

The young seedlings of oat varieties Victory and Anthony raised in 6 inches pots were inoculated with uredospores of races 227, 231 and 240 separately either by applying the inoculum with a flame sterilized needle to the moistened leaves or by single spore or by spraying the uredospores suspension mixed with 2-3 drops of Polyethylene Glycol 400 in two litres of water or by hypodermic syringe as demonstrated by Fleishmann (1964). The inoculated seedlings were kept in incubation chamber for 48 hours and were then transferred to glasshouse bench or in the open. To avoid mixing of the races and other contaminations they were kept in muslin chambers. The inoculations were made at an interval of 15 days. During rainy season besides Victory and Anthony other vars. namely Landhafer, Ukrain, Saia, Santa Fe, Bondvic and Trispernia were also inoculated. The set of plants was transferred to the glasshouse and another set was kept in open.

Telial material collected from the plants that were grown inside and outside the glasshouse were subjected to the following treatments:-

(i) Alternate wetting and drying each day for 30 days, followed by alternate freezing and thawing at room temperature at 3 days interval for 48 hours;

(ii) Soaking overnight and freezing for 150 days, Johnson and Newton (1933);

(iii) Soaking and drying alternately for 24 hours and continuing this for 40 days, later subjecting them to alternate freezing and thawing at 3 day intervals for 48 days and

(iv) Soaking telial material in running water for 5 days and later subjecting them to alternate freezing and thawing at 24 hours interval for 30 days.

For determining the effect of chemicals, telial material was transferred to watch glasses containing 0.5 per cent Sodium-hypochloride and were allowed to remain in each solution for 10, 20 and 30 minutes or in either 0.5 per cent Citric or Lactic acids for 5, 10, 20, 30, 40 and 50 minutes, Zimmer et al.(1961). They were finally transferred to deep freeze where they were stored.

Some fresh telial material was treated with 0.1 and 0.5 per cent solutions of Sulphuric acid for 1, 2, 3, and 5 minutes and later stored in deep freeze.

Telial material was first stored for 30 days in deep freeze and later treated with Sulphuric acid and thus again stored.

In each of the above cases the germination of the teliospores were tested at 3 days interval as for uredospores.

Studies on Host Range

Rust free Agropyron sp., Lolium perenne L., L.temulentum L.(Hordeae), Agrostis royleana Trin., Agrostis sp., Muhlenbergia huegelii Trin., Sporobolus indicus (L.) R.Br. (Agrostideae), Andropogon squerrosus L., Arthraxon sp., Apluda aristata L., Capillipedium parviflorum (R.Br.) Stapf., Cymbopogon martinii (Roxb.) Watts. (Andropogoneae), Cynodon dactylon (L.) Pers. (Chlorideae), Arundinella nervosa Theu. (Malinideae), Brachypodium sylvaticum (Huds.) P.Beauv., Dactylis glomerata L. Festuca gigantia (L.) Vill., F.Myuros L., Helictotrichon asperum (Hunro) Bor, H.virescens (Nees) Henr., Poa annua L., P.nemoralis L. (Festuceae), Phalaris minor Retz. (Phalarideae) were collected from Simla hills, while Chrysopogon sp., C.montanus Trin. I.G.O. 67-17, I.G.O.167 (Andropogoneae), Agrostis canina L. E.C.28114, A.tenuis Sibth. E.C.20647, Oryzopsis miliacea Trin. E.C.32446,

E.C.32996, Phleum sp., E.C.16734, E.C.16738, E.C.16739, E.C.17946, E.C.17847, E.C.18333, P.pratense L. E.C.21246, E.C.21247 (Agrostideae), Arrhenatherum elatius (L.) J.S.et C.B.Presl E.C.17934, E.C.17935, E.C.17936, Avena fotua L. A.sativa L. E.C.19177, A. glauca L. A.strigosa Schreb. (Aveneae), Bromus arvensis L. E.C.28105, B.catharticus Vahl. I.W.65, B.enermis Leys. E.C.20106, E.C.32997, E.C.33211, E.C.33213, E.C.37530, B.japonicus Thunb., B.reperis L. E.C.17940, B.uniloides H.B.K., Dactylis sp.E.C.15125, E.C.15126, I.W.1854, Eragrostis lehmanniana Nees. E.C.37173, Festuca sp.E.C.15123, E.C.16741, E.C.16744, E.C.16745, E.C.17037, E.C.17949, E.C.18329, E.C.18324, I.W.1849, I.W.1850, F.arundinacea Schreb. E.C.28364, F.pratensis Huds. E.C.16733, E.C.17948, E.C.18047, E.C.28362, F.rubra L. E.C.31356, Poa trivalis L. E.C.28151, Vulpia myuros (L.) Gmel. (Festuceae), Agropyron semicostatum Nees. E.C.32999, A.pectiniforme Roem. et Schult. E.C. 33000, Elymus sibricus E.C.15603, E.canadensis L. E.C.26251, Hordeum distichon L. E.C.14489, H.irregulare L. E.C.14491, H. murinum L. E.C.2413, I.W.1712, Lolium sp. E.C.16005, E.C.16127, E.C.16743, E.C.16746, E.C.16747, E.C.16752, E.C.16753, E.C.16754, E.C.16550, E.C.118332, E.C.20647, L.hybridum L. E.C.16753, E.C. 18014, L.italicum A.Br. E.C.28304, L.multiflorum Lamk. E.C.28335, E.C.35641, L.perenne L. E.C.17894, E.C.28301, E.C.28312, E.C. 35639, E.C.35640, E.C.37682 (Hordeae), Ehrharta calycina Rob. E.C.33001, E.C.33007, E.C.33208, E.C.33209, E.cartilaginea J. G.Sm. E.C.33407, Phalaris sp.E.C.15122, E.C.15991, E.C.16756, P. arundinacea L. E.C.28103, P.canariensis L., P.minor Retz. I.W. 484, P.tuberosa L. E.C.16756 (Phalarideae), Cenchrus ciliaris L. I.G.O. 67-15, I.G.O.67-59, Echinochloa colonum (L.) Link., E. frumentacea Link., Panicum antidotale Retz. Pennisetum pedicellatum Trin. I.G.O.56, IG.O.67-43, P.orientale L.C.Rich. I.G.O. 67, P.polystachyon (L.) Schult. I.G.O.67-15 and Digitaria sp. (Paniceae) were either obtained from Plant Introduction Centre, Simla or Indian Grassland and Fodder Research Institute, Jhansi, have been raised in glasshouse. They were allowed to grow in the glasshouse for about one month to determine whether they carried any natural infection of the rusts or not.

The young leaves of these grasses were inoculated with

mixture of races 227, 231 and 240 of crown rust as given on page 6. The grasses on which infection was produced were further tested with individual races 227, 231 and 240 in the same way as described above. Observations were taken after 25 days of inoculations.

Assessment of Losses

In glasshouse studies oat vars. Punjab local and Kent were grown in wooden trays. They were inoculated with uredospores suspension of crown rust starting from seedling stage till flowering or from boot stage till flowering or flag leaf stage till flowering at an interval of 20 days.

In field tests, Punjab local and Kent vars. were grown in four different plots. The plants were inoculated with uredospores suspension of crown rust. The procedure was repeated 3 or 4 times at an interval of about 20 days. In between the beds heavily infected plants of Victory oat were transferred. Control for each plot was kept rust free by spraying the plants with 0.2 per cent Dithane M-45 before inoculations. Plants from each plot were harvested separately, and losses were calculated on the basis of 100 grain weight as suggested by Simons and Browning (1961).

Physiologic Specialisation

For determining the distribution of physiologic races of the P. coronata avenae in Himachal Pradesh, Punjab and Uttar Pradesh, several fields were visited in 5 to 15 locations in each of the three states. Rust infected leaves were collected. They were dried in folds of blotting paper and were brought to the laboratory. Uredospores were scraped and seedlings of Victory oat were inoculated with them, from the inoculum thus raised from each collection differential vars. Anthony, Victoria, Appler, Bond, Landhafer, Santa Fe, Ukrain, Trispernia, Bondvic and Saia were inoculated for race determination, Simons and Murphy (1955). Single spore inoculation were also made on seedlings of Victory from these differentials as and when required. It was repeated several times. Observations were recorded after 15 days of inoculations.

Irradiation in Relation to Pathogenicity of the Rust

Fresh uredospores of race 227 were exposed to Ultra violet and Infra red radiation as described on page 5, were used for inoculating the seedlings of oat var. Victory. When the uredopustules developed, uredospores were collected and were later used for inoculating the differentials. Inoculated plants in each case were incubated and were transferred to glasshouse bench.

Chemical Mutagenesis in Oats

Healthy seeds of oat var. Kent were dehusked, the basal and the distal ends of each seed were cut. The seeds were either dipped in 0.4 per cent Ethyl methanesulphonate (EMS) solution or in Diethyl sulphate (DES) solution. A batch of 3,000 seeds from each treatment were taken out after 24 hours and another batch of 3,000 seeds after 48 hours. The seeds were then washed in running water. The seeds from each treatment were sown in 6 inches clay pots and after 7 days the number of seeds that germinated were counted. The seedlings were tested for the reaction to race 227 of crown rust. The plants that proved to be resistant were allowed to grow till maturity.

Sources of Resistance in Oats

In these studies one hundred and thirty four vars. of oats were tested. Out of these Eagle 2 x C.I.7438, Kopler, Minrus, Avena sativa C.I.7438, Eagle 2 x C.I.4023, C.I.4021, C.I.4025, C.I.5044, C.I.7597, C.I.8111, C.I.9869, Radney, ag 313, ag 351, Clinta 2 x Arkansas, Many were obtained from Dr. D.M.Stewart, Plant Pathologist, University of Minnesota, U.S.A.; N.P.1, N.P.101, Hyb.2, Hyb.3, Hyb.4, P.P.2, Reed 12, Reed 14, Reed 19, Reed 19A, Reed 21, Reed 22, Reed 23, Reed 29, Junagarh Farm 1, Junagarh Farm 2, Kanpur local, Lyallpur local, I-80-40, I-251-32, II-97-84, II-51-9, III-242-56, ~~IX-B-116-36~~ IV-B-16-17, VII-256, VIII-578, X-27, XI-A-325-16, XII-B-93-51, XIII-B-116-36, XIII-B-116-36G, XIII-B-153-2, XIV-76-55, XV-75-73, XV-75-73G, B.S.1, B.S.2, B.S.4, Iowa 103, Iowa 105, Iowa 670, Punjab local, Avon, Abundance, Advocated, Carston, Knota, Laggoon, Neb.1, Plestine,

S.Potato, Boris Opus, Kent, Adlikar, Dale, Ballidue, Flemming Gold, Richland, Jonette, Victory, Joetrain, Algerian, Brunker, Appler, Bond, Overland, Trispernia, Victoria, E.C.15720, E.C. 22025, Clintland 60, Australian local, Coast Black, Bondvic, Landhafer, Santa Fe, Ukrain, Saia, Budha, Gopher, Markton, Mulga, Norton, Reed 10, Algeria, Angnoise, Breenker, Fulgum, Gidque, White Algerian, New Australian and Newzealand were furnished by Plant Introduction Centre, Simla; and I.G.O.67-1, I.G.O.67-2,I.G.O.67-3, I.G.O.67-4, I.G.O.67-5, I.G.O.67-6, I.G. O.67-7, I.G.O.67-8, I.G.O.67-9, I.G.O.67-11, I.G.O.67-12, I.G. O.67-13, I.G.O.67-14, I.G.O.67-15, I.G.O.67-16, I.G.O.67-17, I.G.O.67-18, I.G.O.67-19, I.G.O.67-20, I.G.O.67-21, I.G.O.67-22, I.G.O.67-23, I.G.O.67-68, I.G.O.67-69, I.G.O.67-70 and I.G.O. 67-71 were obtained from Indian Grassland and Fodder Research Institute, Jhansi. These vars. were grown in 6 inches oley pots and were tested against races 227, 231, 240 and S individually.

Cross Protection

The seedlings of oat var. Victory were inoculated with crown rust. To these, rusted leaf pieces of crown rust, P.graminis tritici, P.graminis avenae, P.recondita, P.striiformis, P.sorghi and P.hordei were attached. While for the control healthy leaf pieces of the respective hosts were attached.

The seedlings of oat were inoculated with crown rust, P.graminis avenae; wheat with P.graminis tritici, P.recondita and P.striiformis; maize with P.sorghi and barley with P.hordei. To these oat leaf pieces infected with crown rust were attached. In the control healthy leaf pieces of their respective hosts were attached to the inoculated leaves.

Protection by Cross Inoculation

The seedlings of oat var. Victory were inoculated separately with equal ammount of uredial suspension of P.graminis avenae, P.graminis tritici, P.recondita, P.striiformis, P.sorghi and P.hordei. They were, again inoculated immediately or after 2 or 5 or 7 days with a equal ammount of uredial

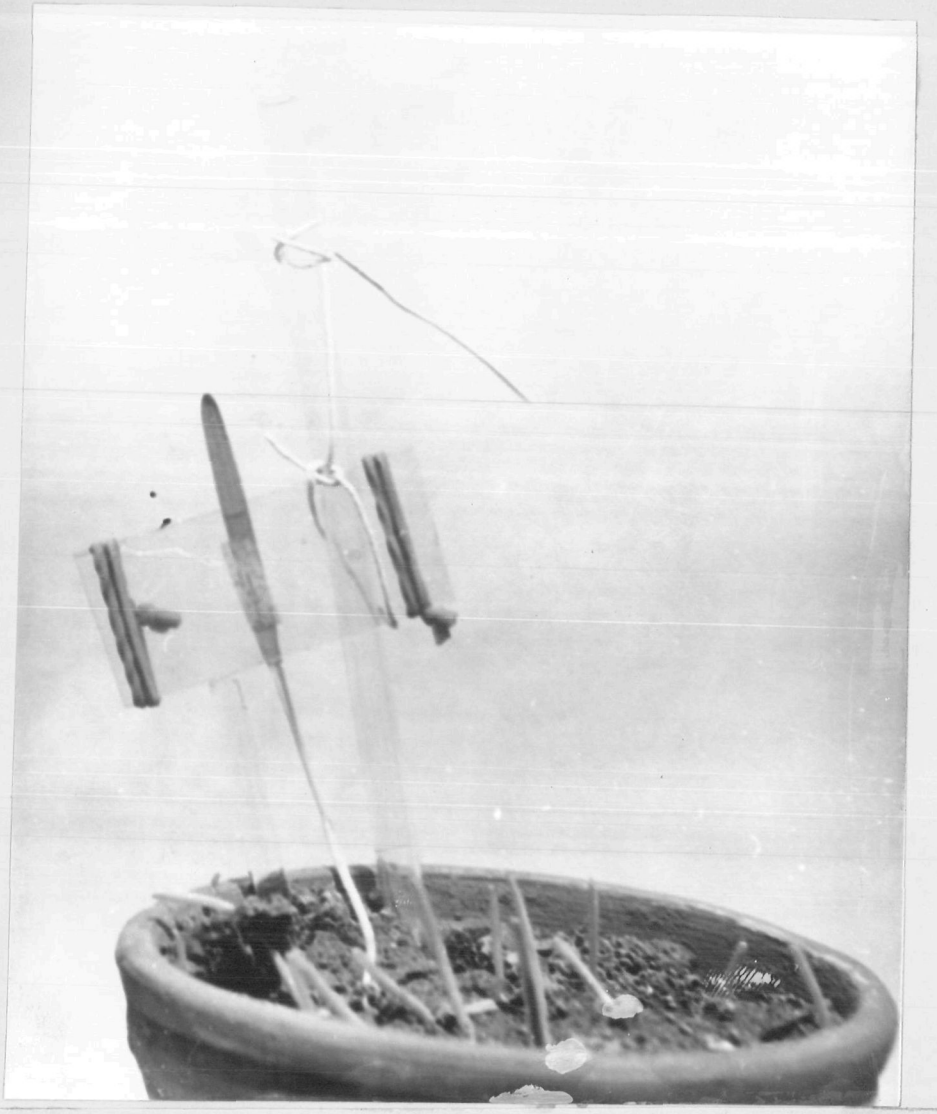

Fig.1: The attachment of rusted leaf piece to inoculated leaf.

suspension of crown rust.

In each case the plants were transferred to glasshouse benches after usual incubation period. Observations were recorded after 15 days of inoculations.

Control by Fungicides

For determining the effect of Dithane Z-31, Dithane Z-45 and MI 339 (supplied by Indofil Chemicals Ltd., Bombay), stock solution was prepared by dissolving 0.5 g in 50 ml of distilled water and subsequently diluting them to different concentrations. Uredospores of crown rust were kept for germination in each case. The seedling of oat var. Victory were inoculated with mixture of races as described for assessment of losses. Immediately after inoculations infected seedlings were sprayed with 0.2 per cent either Dithane Z-31, or Dithane Z-45 or MI 339. The fungicides were applied four times at about 20 days interval in similar fashion.

Breeding for Resistance

The seedlings of oat vars. Landhafer, VIII-570, Punjab local, Gopher, Curt and ag 551 were raised in the glasshouse and also in the field, in such a way that the time of flowering of of each variety coincided. The anthers were removed from the plants that were to be used as female parents and were pollinated by the pollens of the desired male parent.

The following crosses were made:-

Landhafer x Punjab local;
Gopher x Curt;
Gopher x VIII-570
ag 551 x Punjab local.

The F_1 seeds formed as a result of the above crosses were raised in the glasshouse and were tested against race 327 of crown rust. The F_2 progenies were also tested with the above race and the plants that were found to be resistant were retained while the susceptible plants were rejected. Similarly, F_3 families were again tested with the same race, susceptible plants were rejected and the resistant ones were put into further studies. The seeds of the fixed families in the F_3 or in the

F_4 were collected toghether. These were grown in the field along with Punjab local and Kent for studying their agronomic and vegetative characters moreover, single plant selection from each of these fixed families were also made. These were raised in the glasshouse and were later sown in the field along with their parents, Punjab local and Kent at such an interval that their flowering time synchronised. The selected plants namely LH-1 (from Landhafer x Punjab local), GC-8 (from Gopher x Curt), Punjab local and Kent were used for attempting dialle crosses. The F_1's from each cross were tested with race 227 of the crown rust and were allowed to grow to study further some other characters such as number of tillers, height of the best developed plant; number of leaves of this plant; length and width of the best developed leaf; number of nodes and internodes of the same plant; and number of spikelets per inflorescene.

Effect of Plant Extract on the germination of Uredospores

Inhibition of uredospores germination other than crown rust in fungal extract have been reported by several workers, Prasada (1948b), Prasada and Sharma (1964), Ahmad (1968). Recently, Kono (1962) reported that the germination of crown rust uredospores was inhibited in leaf extract of host and non host plants. Hirata (1962) and Ahmad (1969 in press) reported the inhibition of crown rust uredosporos germination in culture filtrates of fungi. The effect of non host plants leaf extract is given in table I.

It is clear from the table I that the germination of uredospores of P.coronata avenae in Standard (S) extract was inhibited in almost all the extracts except Papaver sp. Similarly there was little or no germination in the S/2 concentration of extracts of Thalictrum javanicum, T.reniforme, Cannabis sativa, Datura stramonium, Eucalyptus sp., Oxalis corniculata, O.acetocella, Rumex nepalensis, R.hastatus, Urtica dioica, U.parviflora, Girardinia heterophylla, Geranium sp., G.lucidum, G.divaricatum, G.nepalense, Rhamnus purpureus, R. virgatus, Viola canescens, Vitis himalayana, V.parviflora, Impatience balsamina, Berberis aristata, and B.lycium and poor in Chenopodium album and Pueraria sp., and high in Papaver sp. (75 per cent).

The extracts of Urtica dioica and Papaver sp.was found to have pH 7.5 and 6.4 respectively. The inhibition of uredospores germination in the former may be due to the high alkalinity ... of the extract when compared to the latter. Studies on paper chromatography to determine the reason for inhibition of uredospores germination could not be carried out.

Table I: Effect of plant extract on the germination of uredospores of *P.coronata avenae*

Name of the plants	Family	Uredospores germination (%) Standard	S/2
Thalictrum javanicum	*Ranunculaceae*	0	1-2
T.reniforme	"	0	1-2
Cannabis sativa	*Moraceae*	0	0
Chenopodium album	*Chenopodiaceae*	0.5	15-20
Datura stramonium	*Solanaceae*	0	0
Eucalyptus sp.	*Myrtaceae*	0	0
Oxalis corniculata	*Oxalidaceae*	0	1-2
O.acetocella	"	0	0
Rumex nepalensis	*Polygonaceae*	0	0
R.hastatus	"	0	0.1-0.4
Pueraria sp.	*Leguminoceae*	1-2	10-15
Urtica dioica	*Urticaceae*	0	0
U.parviflora	"	0	0
Girardinia heterophylla	"	0	0
Geranium sp.	*Geraniaceae*	0	0
G.lucidum	"	0	1-2
G.divaricatum	"	0	1-2
G.nepalense	"	0	2-4
Rhamnus purpureus	*Rhamnaceae*	0	0
R.virgatus	"	0	0
Viola canescens	*Violaceae*	0	2-6
Vitis himalayana	*Vitaceae*	0	0
V.parvifolia	"	0	1-2
Papaver sp.	*Papaveraceae*	55-60	75
Impatiens balsamina	*Balsaminaceae*	0	3-5
Berberis aristata	*Berberidaceae*	0	0
B.lycium	"	0	0
Control		87	87

Effect of Ultra Violet and Infra Red Rays on Uredospores Germination

It is clear from Fig.2 that exposure of uredospores to UV rays brought about a marked decline in the germinability of uredospores. The germination was 35 per cent after 40 min. of exposure; 15 per cent after 80 min. and 0 per cent after 110 min.

The effect of IR (Fig.2) was more drastic as all the spores succumbed even after 10-15 minutes exposure.

Factors Influencing the Formation and Germination of Teliospores

The formation of teliospores and their germination in cereal rusts have been studied by several workers, Magnus (1891), Gassner (1915), Parker (1918), Butler (1918), Hoerner (1921,1922), Raines (1922), Baily (1925), Parson (1927), Waters (1928), Peturson (1930), Mehta (1933, 1940), Murphy (1935), Prasada (1948), Zimmer and Schafer (1961), Zimmer et al.(1960, 1961).

It is evident from table II that as a result of inoculating oat vars. Ukrain, Saia, Landhafer, Santa Fe, Bond and Trispernia with race 227, telia were produced on Landhafer, Santa Fe and Trispernia; on Saia with race 231 and only on Ukrain with race 240. In each case the time required for the production of telia was less at 22^0-28^0 C. than at 18^0-22^0 C. Telial production occurred on relatively resistant plants irrespective of the age of the plants.

All the three races produced telia on seedlings of Victory and Anthony as well as on adult plants, although both these were highly susceptible (Table III). It is interesting to note that the time required for production of telia by the three races on resistant and susceptible plants did not differ much.

It is clear from tables IV,V and VI that despite subjecting freshly formed teliospores to different physical and chemical treatments the teliospores failed to germinate. On the other hand, the overwintered teliospores germinated readily in each case.

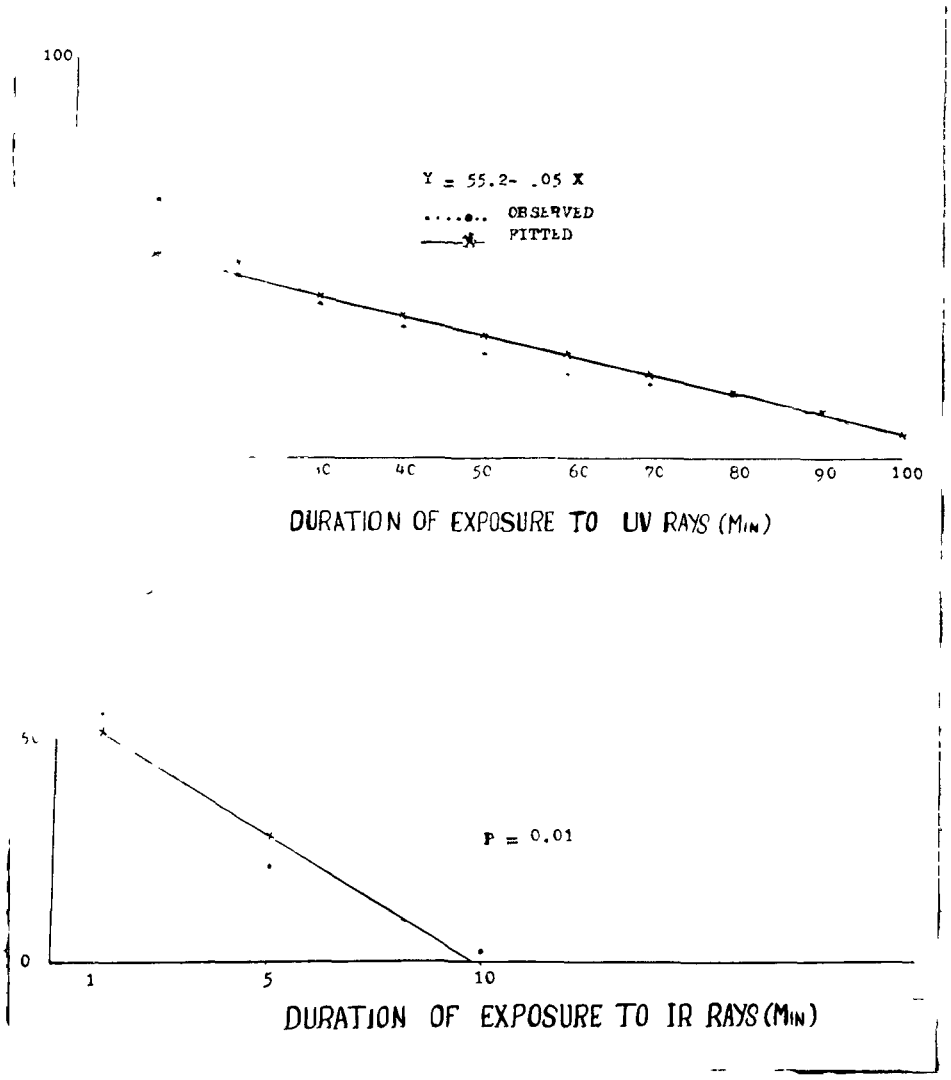

Fig.2: The effect of exposure to Ultra violet and Infra red rays on the germination of uredospores of crown rust.

Table II: Days after inoculations, telia of crown rust were formed on seedlings and mature plants on six vars. of oats at 18-22°C. and 22-28° C.

Race	Varieties	Reaction	18-22°C. Seedling	18-22°C. Mature plant	22-28°C. Seedling	22-28°C. Mature plant
227	Ukrain	S	-	-	-	-
	Saia	S	-	-	-	-
	Landhafer	R	15	18	13	15
	Santa Fe	R	14	17	13	16
	Bond	R	-	-	-	-
	Trispernia	R	14	16	12	14
251	Ukrain	S	-	-	-	-
	Saia	R	16	18	13	16
	Landhafer	R	-	-	-	-
	Santa Fe	R	-	-	-	-
	Bond	R	-	-	-	-
	Trispernia	R	-	-	-	-
240	Ukrain	R	18	22	13	15
	Saia	R	-	-	-	-
	Landhafer	R	-	-	-	-
	Santa Fe	R	-	-	-	-
	Bond	R	-	-	-	-
	Trispernia	R	-	-	-	-

Table III: Days after inoculations, telia of crown rust were observed on seedlings and mature plants of susceptible vars. Victory and Anthony at 22-28° C.

Race	Varieties	Reaction	Seedlings	Mature plants
227	Victory	S	15	19
	Anthony	S	16	20
231	Victory	S	15	18
	Anthony	S	15	20
240	Victory	S	16	21
	Anthony	S	16	20

Table IV: Results showing the effect of different treatments on the germination of fresh and overwintered teliospores of P. coronata avenae.

	Treatment	Days	Germination (%)
Fresh	Alternate wetting and drying for 24 hrs. each + Alternate freezing and thawing for 3 days each	30 + 48	0
	Soaking in water for 24 hrs. and freezing followed by alternate freezing and thawing	150	0
	Soaking in water and drying 24 hrs. each + Alternate freezing and thawing for 72 hrs. each	40 + 48	0
	Soaking in water for 72 hrs. followed by freezing and thawing 24 hrs. each	30	0
Over-wintered	Without any treatment		
	Wetting and drying for 24 hrs. each	3	25

Table V: Results showing the effect of different chemicals on the germination of fresh teliospores of *P.coronata avenae*.

Treatment		Percentage germination of Sodium hypochloride treated teliospores. Concentration (%) and time in minute					
		0.5			1.0		
		10	20	30	10	20	30
Citric acid 0.5 %	5	0	0	0	0	0	0
	10	0	0	0	0	0	0
	20	0	0	0	0	0	0
	30	0	0	0	0	0	0
	40	0	0	0	0	0	0
	50	0	0	0	0	0	0
Lactic acid 0.5 %	5	0	0	0	0	0	0
	10	0	0	0	0	0	0
	20	0	0	0	0	0	0
	30	0	0	0	0	0	0
	40	0	0	0	0	0	0
	50	0	0	0	0	0	0
Overwintered untreated							45

Table VI: Results showing the effect of Sulphuric acid on the germination of fresh teliospores of P.coronata avenae.

Treatment	Germination (%) of teliospores in different duration (Min.) of treatment with.			
	1	2	3	5
Sulphuric acid and frozen for 30 days	0	0	0	0
Frozen for 30 days and treated with Sulphuric acid	0	0	0	0
Overwintered, untreated				35

Studies on Host Range

The hills in India are rich in the grass flora, both naturalised and introduced ones, and they harbour many rusts. Butler (1918), Butler and Bisby (1931), Misra, Ahmad and Singh (1965,1968) obtained Puccinia graminis fers. P.recondita and P.striiformis on several grasses. On the other hand, there are grasses which function as collateral hosts to variety of cereal rusts, Mehta (1940), Prasada (1946c, 1951). Vasudeva et al. (1953), Lele and Rao (1961), Misra and Lele (1963), Ahmad and Singh (1967).

Recently Ahmad, Misra and Singh (1968) reported the existence of P.coronata agrostis and P.coronata festucae on Agrostis royleana and Festuca gigantia respectively, therefore, it necessitated to determine whether the grasses growing in the vicinity of Simla harbour crown rust or not.

Rust failed to develop on Agropyron sp., Lolium perenne, L.temulentum, Agrostis royleana, Arthraxon sp., Aplude aristata, Agrostis sp., Andropogon squarrosus, Sporobolus indicus, Capillipedium parviflorum, Cymbopogon martinii, Cynodon dactylon, Arundinella nervosa, Brachypodium sylvaticum, Dactylis glomerata, Festuca gigantia, F.myuros, Poa annua, P.nemoralis, Phalaris minor, Phalaris sps. E.C.16122, E.C.15991, E.C.16756, P.tubrosa E.C. 16756, Chrysopogon sp., C.montanus I.G.O. nos.67-17, 167, Agrostis canina E.C.26114, A.tenuis E.C.20674, Oryzopsis miliacea E.C.32446, Phleum sp. E.C.nos. 16734, 16738, 16739, 17847, 17946, 18353, P.pratense E.C.21246, E.C. 21247, Arrhenatherum elatius E.C. nos. 17934, 17955, 17936, Bromus arvensis E.C.20105, B.catharticus I.W.65, B.enermis E.C.nos. 20106, 32997, 33211, 33213, 37530, B.japonicus, B.reperis E.C.17940, B.uniloides, Dactylis sp. E.C.15125, E.C.15126, I.W.1854, Eragrostis lehmanniana E.C.37157, Festuca sps. E.C.nos. 15123, 16741,

16744, 16745, 17037, 17949, 18329, 18324, I.W.1849, I.W. 1850, F. arundinacea E.C. 28364, F.pratensis E.C. nos. 16733, 17483, 18047, 28362, F.rubra E.C. 31356, Poa trivalis E.C. 28151, Agropyron semicostatum E.C.32999, A. pectiniforme E.C.33000, Elymus sibricus E.C.15603, A. canadensis E.C. 26251, Lolium sp. E.C. nos. 16005, 16127, 16743, 16746, 16747, 16752, 16753 16754, 18330, 18332, 20647, L. hybridum E.C. 16753, E.C. 18014, L. italicum E.C. 28304, L. multiflorum E.C. 28355, E.C. 35641, L. perenne E.C. nos. 17489, 28301, 28312, 35639, 35640, 37682, Ehrharta calicina E.C. nos. 33001, 33007, 33208, 33209, E. cartilaginea E.C. 33407, Cenchrus ciliaris I.G.O. 67.15, I.G.O. 67-59, Echinocloa colonum , E. frumentacea, Panicum antidotale, Pennisetum pedicellatum I.G.O. nos. 56, 67-32, 67-43, P. orientale I.G.O. 67, P. polystachyon I.G.O. 67-15, Digitaria sp. when they were inoculated with mixture of races 227, 231 and 240 of P.coronata avenae. On the other hand Avena elatior, A. fatua, A. glauca, A. sativa, A. strigosa, Helictotrichon asperum, H. virescens, Hordeum distichon, H. irregulare, H. murinum, Muhlenbergia huegelii, Phalaris arundinacea, P. minor and Vulpia myuros showed varying degrees of infection. The grasses on which the infection was produced by these races were subsequently tested with mixture as well as individual races 227, 231 and 240 and the reactions are presented in table VII.

It is clear from table VII that A. elatior, A. fetua, A. glauca, A. sativa, A. strigosa, Muhlenbergia

huegelii and Vulpia myuros were highly susceptible to mixture as well as to the three races individually, as the infection type ranged (2-4) on them. P. canariensis and P. minor was susceptible to the mixture and to race 227 only. H. asperum and H. virescens showed either 0 or 0; or in some cases type 1 reaction to mixture as well as to individual races.

Table VII: * Infection types produced on the grasses against races 227, 231 and 240 of P.coronata avenae and their mixture.

Grasses	Mixture	Races 227	231	240
Avena elatior E.C.18339	3-4	4	3-4	3-4
A.fetua	3-4	4	2-3	2-3
A.glauca	3-4	4	4	3-4
A.sativa E.C.19177	3-4	4	3-4	2-3
A.strigosa	4	4	2-3	2-3
Helictotrichon asperum	0;-1	0;	0;-1	0;
H.virescense	0;-1	0;-1	0;	0;
Hordeum distichon E.C.14489	0;-1	0;	0;	0;
H.irregulare E.C.14491	0;-1	0;-1	0	0
H.murinum I.W.1712	0;-1	0;	0	0
H.murinum E.C.2413	0;-1	0;-1	0;-1	0
Muhlenbergia huegelii	4	3-4	3-4	3-4
Phalaris arundinacea E.C.28103	0;-1	0;-1	0;	0;-1
P.canariensis	2-3	2-3	0;-1	0;-1
P.minor I.W.484	2-3	2-3	0;-1	0;
Vulpia myuros	4	3-4	2-3	2-3

* Infection types as given by Stakman et al. (1962)

Assessment of Losses

Considerable losses due to crown rust have been reported, Eglits (1928), Murphy (1935a), Buchholtz (1946), Atkins and Mc Fadden (1947). According to Pammel (1907) about 50 per cent of oat crop was destroyed by crown rust.

It is clear from table VIII that repeated inoculations (3-4 times) of oat var. Punjab local with mixture of races of crown rust at the seedling and boot stage brought about losses to 90 and 60 per cent respectively. Similarly, the losses of var. Kent when inoculated at the seedling and boot stage were 93 and 68 per cent repectively. When however, the inoculations were made only either at seedling or boot or flag leaf stage, the losses were negligible (5 per cent) on both the varieties.

Similarly, losses on Punjab local and Kent were 40 and 50 per cent respectively, when they were repeatedly inoculated (4-5 times) under field conditions, Fig.3.

Physiologic Specialisation

In Europe, Klebahn (1892) divided *P.coronata* into two species, *P.coronata* (Corda) Kleb. and *P.coronifera* Kleb., the former infecting the aecidial host *Rhamnus frangula* L. and the latter *R.cathartica* L. Later Klebahn (1895,1896,1898,1912), Eriksson (1897,1909) and Muhlethaler (1910,1911) divided the two species into *formae speciales* on the basis of infection to certain uredial hosts. They reported five specialised forms of *P.coronata* and nine of *P.coronifera* the latter including the f.sp.*avenae* on oats.

Klebahns classification based on the aecidial host reaction was questioned by many workers, Mehlus *et al* (1922), Dietz (1926), Fraser and Ledingham (1933), Murphy (1935), Straib (1937), Brown (1938) who in consequence retained all the *formae speciales* distinguished by them under the original species *P.coronata* Corda since they found that

Table VIII: Losses in grain yield of vars. Punjab local and Kent as a result of inoculating them with mixture of races 227, 231 and 240 of crown rust at different stages of growth of plants.

Oat vars. inoculated	Stage of growth at the time of inoculation	Number of times inoculated	Infection (%)	Losses (%)
Punjab local	Seedling	1	0	0
		4-5	100	90
	Boot	1	10	7
		3-4	100	60
	Flag leaf	1	100	3
Kent	Seedling	1	0	0
		4-5	100	93
	Boot	1	18	10
		3-4	100	68
	Flag leaf	1	100	5

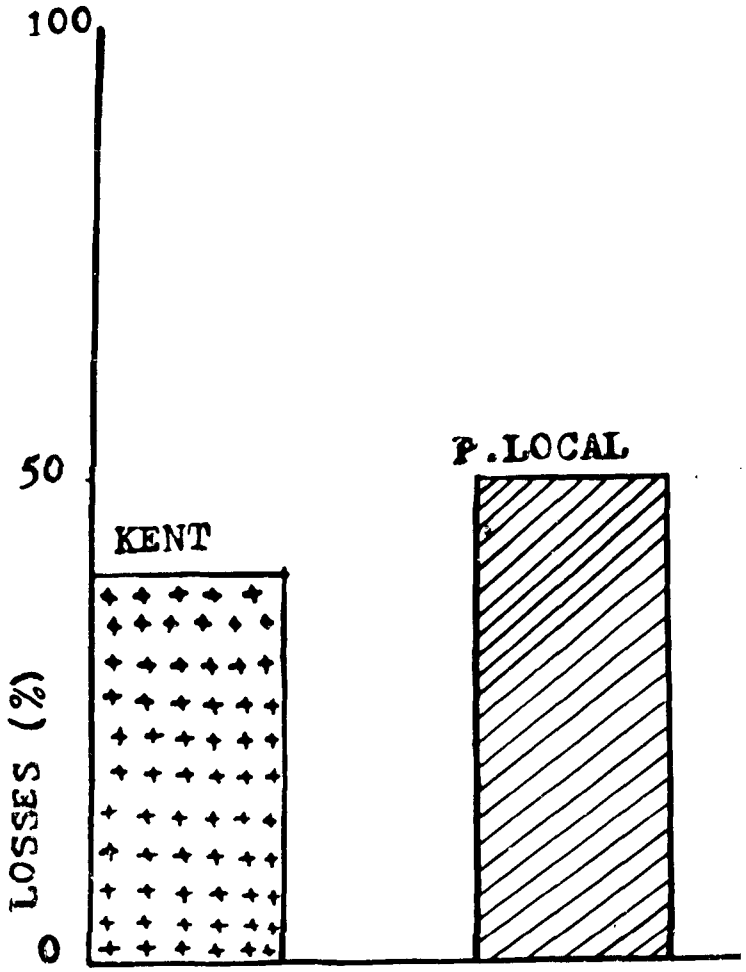

Fig.3: Losses in grain yield of oat vars.Punjab local and Kent to crown rust infection.

most of the formae speciales reported by Klebahn infect both R.frangula and R.cathartica.

According to Griffiths (1958) P.coronata comprised of about 14 so called formae speciales . Peturson (1954) and Payak and Misra (1963) have added two more forms namely, P.coronata secalis and P.coronata himalensis respectively. Recently Ahmed et al. (1968) reported P.coronata festucae thus bringing the total to17 formae speciales or varieties of the rust.

Moerner (1919) distinguished 4 races of P.coronata avenae on the basis of differential reactions of two oat vars. namely Naukura Rust Proof and Green Russian. Straib (1937) from England identified 4 races on 11 oat vars. Also many investigators have reported several races of the rust on arbitarily selected differentials, Popp (1926), Frenzel (1930), Murphy (1930), Stakman et al. (1935), Murphy (1935.) using 13 oat vars. as standard differentials identified 113 races. These vars. have been used for race identification till Simons and Murphy (1955) reported a new set of 10 oat vars. as standard differentials. They compared the two sets of differentials and found that new set (10 vars.) is more reliable than 13 vars. differentials. In India, Payak and Misra (1963) and Misra et al. (1964) reported the existance of races 227, 231 and 240.

Table IX shows the result of inoculating the 10 differential oat vars. recommended by Simons and Murphy (1955) by samples collected from Himachal Pradesh, Punjab and Uttar Pradesh. It is clear that races 227 and 231 were found out of 233 samples analysed from Himachal Pradesh; races 227, 231 and 240 from 292 samples from the Punjab; and races 227, 231, 240 and 8 out of 370 samples from Uttar Pradesh. Race 240 occurred during 1964-65, 1966-67, but not during 1967-68. However, during 1966-67 besides the races 227, 231 and 240 another strain was obtained which differed from the races hitherto described.

Table IX: Physiologic races of P.coronata avenae identified from Himachal Pradesh, Punjab and Uttar Pradesh during 1964-65, 1965-66, 1966-67, 1967-68.

State	Year	Number of samples analysed	Races met with
Himachal Pradesh	1964-65	65	227, 231
	1965-66	35	227, 231
	1966-67	78	227, 231
	1967-68	55	227, 231
	Total	233	
Punjab	1964-65	32	227, 231
	1965-66	63	227, 231
	1966-67	117	227, 231, 240
	1967-68	80	227, 231, 240
	Total	292	
Uttar Pradesh	1964-65	75	227, 231, 240,
	1965-66	60	227, 231, 240
	1966-67	90	227, 231,240,S
	1967-68	145	227, 231, S
	Total	370	

The frequency of occurrence of these races are given in Fig. 4. It is clear from Fig.4 that race 227 has been more prevelent in Himachal Pradesh, Punjab and Uttar Pradesh upto 1966-67. Race 240 could not be isolated from Himachal Pradesh, it was confined to Punjab during 1964-65 and 1965-66 and in Uttar Pradesh during 1967-68. During 1966-67 a collection from Nagina (U.P.) on local oat variety yielded an isolate quite different from the previously reported races. However, its frequency of occurrence was rather low (1.3 per cent), but during the following year its frequency of occurrence was as high as 48.3 per cent. Moreover, the differences of reaction of this isolate were so consistent therefore, it has been arbitarily designated as race S. It is also clear from Fig.4 that there has been considerable shifts in the population of races when comparisions are made with respect to population of different races in a particular state or the year. During 1966-67 the population of race 231 increased considerably and was almost twice then in 1965-66. The reaction of this race and other races reported from India are given in table X.

It is clear from table X that the race S differs from other races in its pathogenicity on Landhafer, Santa Fe and Bondvic.

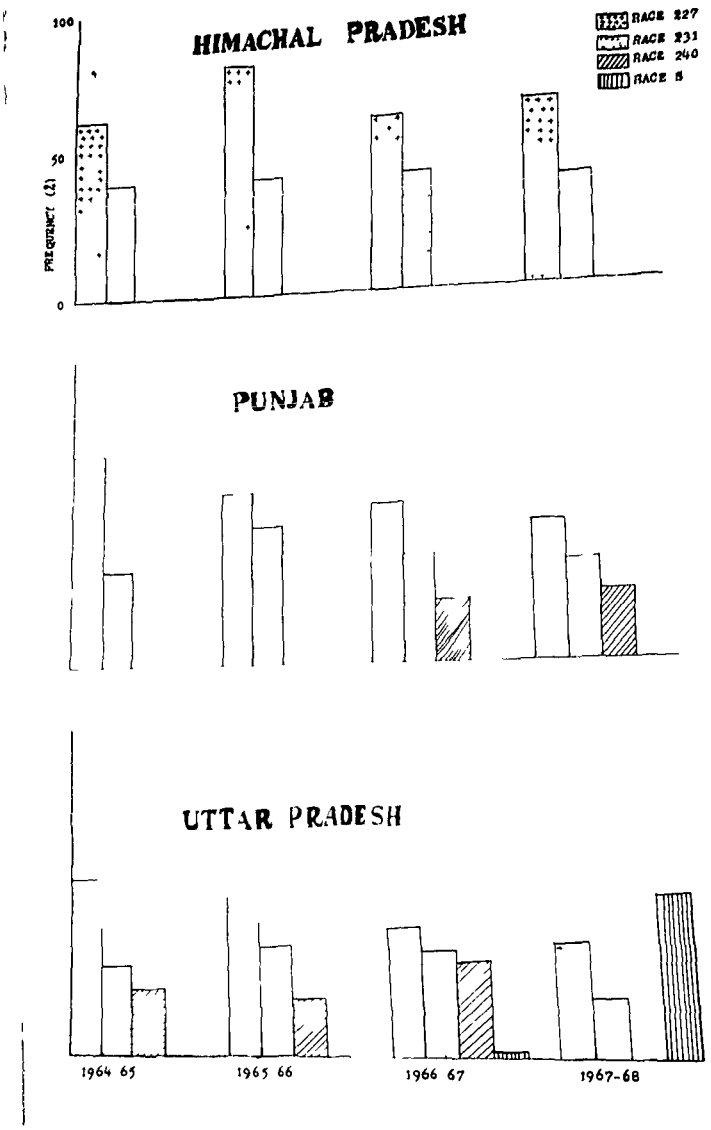

Fig.4: Frequency of occurrence of crown rust races within different states during 1964-1968.

Table X: Comparative reactions* of the four races of P.coronata avenae from India on International differentials.

Race	Anthony	Victoria	Appler	Bond	Landhafer	Santa Fe	Ukrain	Trigonia	Bondvic	Sela
227	S	R	S	R	R	R	S	R	R	S
231	S	R	R	R	R	R	S	R	R	R
240	S	R	R	R	R	R	R	R	R	R
S	S	R	S	R	I	S	R	R	I	S

* Reactions as given by Murphy (1935b).

Irradiation in Relation to Pathogenicity of the Rust

Knowledge pertaining to origin of physiologic races through mutation, hybridization and heterocaryosis have been reviewed, Reed (1935), Craige (1940), Johnson (1946), Stakman and Harrar (1956). Races arise as a result of hybridization, Craige (1940), Waterhouse (1929,1932), Newton,Johnson and Brown (1930), Cotter (1932), Stakman et al. (1934), Watson (1957a); Mutation, Stakman,Levine and Cotter (1930), Gassner and Straib (1932), Roberts (1936), Newton and Johnson (1939), Watson (1957b), Zimmer and Schafer (1959), Zimmer,Schafer and Patterson (1962,1963), Ahmad and Singh (1969), Singh,Misra and Ahmad (1969); heterocaryosis, Nelson,Wilcoxon and Christensen (1955), Nelson (1956).

Recently Griffiths and Carr (1961) have contributed towards our knowledge of the origin of the physiologic races in Puccinia coronata avenae by induced mutation. Induced mutation in rusts by the application of Ultra violet and and Gamma rays have also been reported, Flor (1956), Schwinghamer (1957).

It is evident from table XI that exposure of uredospores to UV for 10 and 20 min. did not bring any change in reaction on the differentials. However, exposure for 30,40, 50,60 and 70 min. the reaction on Landhafer and Santa Fe became intermediate from resistant and on the remaining there was no marked change. Exposure for 80,90 and 100 min. resulted in bringing about a change in reaction from resistant to intermediate on Bondvic.

To determine whether these changes in pathogenicity were genotypic or phenotypic, the uredospores from each category of pustules whenever change in reactions were produced as a result of irradiation were isolated and mutiplied separately and again differentials were inoculated.

The results of this experiment are given in table XII which clearly show that the changes were induced as a result of irradiation were genotypic, as all the subsequent tests revealed the same pathogenicity of the isolates.

Table XI: Infection types* produced on differentials by UV irradiated cultures of race 227 of *P. coronata avenae*

UV exposure in (Min.)	Anthony	Victoria	Appler	Bond	Landhafer	Santa Fe	Ukrain	Trispernia	Bondvic	Sala
10	S	R	S	R	R	R	S	R	R	S
20	S	R	S	R	R	R	S	R	R	S
30	S	R	S	R	I	I	S	R	R	S
40	S	R	S	R	I	I	S	R	R	S
50	S	R	S	R	I	I	S	R	R	S
60	S	R	S	R	I	I	S	R	R	S
70	S	R	S	R	I	I	S	R	R	S
80	S	R	S	R	I	I	S	R	I	S
90	S	R	S	R	I	I	S	R	I	S
100	S	R	S	R	I	I	S	R	I	S
Non irradiated race 227	S	R	S	R	R	R	S	R	R	S

* Infection types as given by Murphy (1935).

Table XII: Infection types produced by the isolates from Landhafer, Santa Fe and Bondvic on differentials.

Isolate	Anthony	Victoria	Appler	Bond	Landhafer	Santa Fe	Ukrain	Trimmarnia	Bondvic	Kale
Landhafer (2) Isolate 1-9	S	R	S	R	R	R	S	R	R	S
Landhafer (3) Isolate 1-19	S	R	S	R	I	I	S	R	R	S
Santa Fe (2) Isolate 1-11	S	R	S	R	R	R	S	R	R	S
Santa Fe (3) Isolate 1-27	S	R	S	R	I	I	S	R	I	S
Bondvic (2) Isolate 1-13	S	R	S	R	R	R	S	R	R	S
Bondvic (3) Isolate 1-31	S	R	S	R	I	I	S	R	I	S
Race 227	S	R	S	R	R	R	S	R	R	S

Uredospores exposed to IR failed to bring about any change in the pathogenicity of race 227 on the differentials, table XIII.

Chemical Mutagenesis in Oats

Disease reaction of oats to crown rust altered as a result of application of certain chemicals, Simons (1955) and Ahmad and Singh (1968). Mc Mullen (1965) also reported that Ethylemethane sulphonate (EMS) brought about mutation in oats for resistance to stem rust of oat.

It is clear from table XIV that the number od seeds that germinated in 0.4 per cent solution of EMS and DES have been 2,280 and 2,550 respectively, out of 3,000 seeds for each that were treated for 24 hours with the two chemicals. Treating the seeds for 48 hours proved to be fatal in each case.

Seedlings raised from EMS treated seeds when inoculated with race 227 only 5 out of 2,280 were found to be resistant and the remaining were susceptible. Similarly, seedlings raised after treatment for 24 hours with DES on inoculations 2,534 were susceptible, 3 intermediate and 13 were found to be resistant (Table XIV).

Table XIII: Infection types* produced by 3 Infra red (IR) irradiated cultures of race 227 of P.coronata avenue.

IR exposure in (min.)	Anthony	Victoria	Appler	Bond	Landhafer	Santa Fe	Ukrain	Trisporula	Bondvic	Sala
1	S	R	S	R	R	R	S	R	S	S
5	S	R	S	R	R	R	S	R	S	R
10	S	R	S	R	R	R	S	R	S	R
Non irradiated race 227	S	R	S	R	R	R	S	R	S	R

* Infection types as given by Murphy (1935).

Table XIV: Reaction of race 227 of P.coronata avenae on seedlings of oat var.Kent that developed after treating the seeds with 0.4 per cent Ethylemethane sulphonate (EMS) and Diethyle sulphate (DES) for different durations.

Treatment	EMS					DES				
	Number of seeds sown	Number of seedlings developed and tested	Reaction R	I	S	Number of seeds sown	Number of seedlings developed and tested	Reaction R	I	S
Kent										
48 hrs.	3,000	3	0	0	3	3,000	5	0	0	5
24 hrs.	3,000	2,280	5	0	2,275	3,000	2,550	13	3	2,534
Untreated	100	98	0	0	98	100	96	0	0	96

Sources of Resistance in Oats

An attempts to find out sources of resistance in oats have been made against crown rust in various parts of the world by inoculating the seedlings and adult plants of cultivated and non-cultivated Avena species, Peturson (1935,1944), Shands (1952), Ivanoff (1953), Earhart and Moseman (1953), Simons (1954,1955a,1957,1959), Williams and Verma (1956), Wahl (1958), Simons,Wahl and Silva (1962) and Dinoor and Wahl (1963).

Since races 227, 231 and 240 are widespread in certain parts of India, Payak and Misra (1963) and Misra et al.(1964), and the discovery of a new race S given on page 32 necessiated the search for resistance in 88 vars. tested earlier by Misra,Singh and Ahmad (1965) and additional 46 vars. against four races of the crown rust.

It is clear from table XV that oat vars. from 1 to 14, 17 to 25, 29 to 40, 42, 44 to 63, 65 to 75, 95 to 114, 116 to 120, 128 to 132 and 134 were susceptible; while vars. at serial nos. 16, 27, 76, 78, 82 and 126 were resistant to all the races. Reactions on the remaining vars. varied. They were either resistant to races 227, 231 and 240 or intermediate or susceptible. It is intresting to note that all these vars. were susceptible to race S.

Table XV: Reactions of 134 cultivated oat seedlings to races 227, 231, 240 and S of P.coronata avenae

S.No.	Varieties	Races			
		227	231	240	S
1	2	3	4	5	6
1	N.P.1	S	S	S	S
2	N.P.101	S	S	S	S
3	Hyb. 2	S	S	S	S
4	Hyb. 3	S	S	S	S
5	Hyb. 4	S	S	S	S
6	P.P. 2	S	S	S	S
7	Reed 12	S	S	S	S
8	Reed 14	S	S	S	S
9	Reed 19	S	S	S	S
10	Reed 19A	S	S	S	S
11	Reed 21	S	S	S	S
12	Reed 22	S	S	S	S
13	Reed 23	S	S	S	S
14	Reed 29	S	S	S	S
15	ag 313	I	I	I	S
16	ag 331	R	R	R	R
17	Junagarh Farm 1	S	S	S	S
18	Junagarh Farm 2	S	S	S	S
19	Kanpur local	S	S	S	S
20	Lyallipur local	S	S	S	S
21	I-251-32	S	S	S	S
22	II-97-84	S	S	S	S
23	II-51-9	S	S	S	S
24	III-242-56	S	S	S	S
25	IV-B-16-17	S	S	S	S
26	I-30-40	I-S	I-S	I	S
27	VIII-576	R	R	R	R
28	X-27	I	I	R	S
29	XI-A-24-30	S	S	S	S
30	XI-A-325-16	S	S	S	S

1	2	3	4	5	6
31	XII-B-93-51	S	S	S	S
32	XIII-B-116-36	S	S	S	S
33	XIII-B-116-360	S	S	S	S
34	XIII-B-153-2	S	S	S	S
35	XIV-76-55	S	S	S	S
36	XV-75-73	S	S	S	S
37	XV-75-736	S	S	S	S
38	B.S. 1	S	S	S	S
39	B.S. 2	S	S	S	S
40	B.S. 4	S	S	S	S
41	Iowa 103	I-S	R-I	R	S
42	Iowa 105	S	S	S	S
43	Iowa 670	S	I-R	R	S
44	Abundance	S	S	S	S
45	Advocated	S	S	S	S
46	Carston	S	S	S	S
47	Knote	S	S	S	S
48	Lagoon	S	S	S	S
49	Neb. 1	S	S	S	S
50	Plalestine	S	S	S	S
51	S.Potato	S	S	S	S
52	Boris Opus	S	S	S	S
53	Kent	S	S	S	S
54	Adlikar	S	S	S	S
55	Dale	S	S	S	S
56	Ballidue	S	S	S	S
57	Avon	S	S	S	S
58	Flemming Gold	S	S	S	S
59	Eagle 2 x C.I.7436	S	S	S	S
60	Eagle2 x C.I.4025	S	S	S	S
61	C.I.7438	S	S	S	S
62	C.I.4021	S	S	S	S
63	C.I.4023	S	S	S	S

1	2	3	4	5	6
64	Clinta 2 x Arkansas	S	S	S	S
65	C.I.5044	S	S	S	S
66	C.I.7597	S	S	S	S
67	C.I.8111	S	S	S	S
68	C.I.9889	S	S	S	S
69	Kopler	S	S	S	S
70	Minrus	S	S	S	S
71	Avena sativa	S	S	S	S
72	Richland	S	S	S	S
73	Jonette	S	S	S	S
74	Victory	S	S	S	S
75	Anthony	S	S	S	S
76	Victoria	R	R	R	R
77	Appler	S	R	R	S
78	Bond	R	R	R	R
79	Landhafer	R	R	R	I
80	Santa Fe	R	R	R	S
81	Ukrain	S	S	R	S
82	Triopernia	R	R	R	R
83	Bondvic	R	R	R	I
84	Saia	S	R	R	S
85	Budha	I-S	R-I	R	S
86	Gopher	S	S	R	S
87	Markton	S	S	I-R	S
88	Mulga	I-S	R	R	S
89	Norton	S	S	R	S
90	Reed 10	S	S	R	S
91	Algeria	I-S	I-R	R	S
92	Angnoise	I	I	R	S
93	Breenker	S	I	R	S
94	Fulgum	S	I-S	R	S
95	I.C.O. 67-1	S	S	S	S
96	I.C.O. 67-2	S	S	S	S

1	2	3	4	5	6
97	I.G.O. 67-4	S	S	S	S
98	I.G.O. 67-5	S	S	S	S
99	I.G.O. 67-6	S	S	S	S
100	I.G.O. 67-7	S	S	S	S
101	I.G.O. 67-8	S	S	S	S
102	I.G.O. 67-9	S	S	S	S
103	I.G.O. 67-11	S	S	S	S
104	I.G.O. 67-12	S	S	S	S
105	I.G.O. 67-13	S	S	S	S
106	I.G.O. 67-14	S	S	S	S
107	I.G.O. 67-15	S	S	S	S
108	I.G.O. 67-16	S	S	S	S
109	I.G.O. 67-17	S	S	S	S
110	I.G.O. 67-18	S	S	S	S
111	I.G.O. 67-19	S	S	S	S
112	I.G.O. 67-20	S	S	S	S
113	I.G.O. 67-21	S	S	S	S
114	I.G.O. 67-23	S	S	S	S
115	I.G.O. 67-68	I	R	R	S
116	I.G.O. 67-69	S	S	S	S
117	I.G.O. 67-70	S	S	S	S
118	I.G.O. 67-71	S	S	S	S
119	Algerian	S	S	S	S
120	Brunker	S	S	S	S
121	Gidgué	S	S	R	S
122	White Algerian	S	S	I	S
123	New Australian	I	R	I	S
124	Hadney	I	I	I	S
125	Newzealand	I	R	R	S
126	Overland	R	R	R	R
127	Kany	S	S	I	S
128	E.C.15720	S	S	S	S

1	2	3	4	5	6
129	E.C.22025	S	S	S	S
130	Clintland 60	S	S	S	S
131	Australian local	S	S	S	S
132	Coast Black	S	S	S	S
133	VII-265	I-S	I-S	I	S
134	Punjab local	S	S	S	S

* Infection types as given by Murphy (1935).

Cross Protection

Yarwood (1954) reported marked reduction in infection in bean and snap dragon rust when rusted leaves were attached to freshly inoculated leaves. However, the attachment of rusted bean leaves to freshly inoculated leaves with powdery mildew, or bean anthracnose or Tobacco mosaic virus failed to bring about any appreciable effect on infection. This led Yarwood to conclude that the germinating uredospores produced substances which were toxic to certain rusts and were volatile in nature. Allen (1955) also demonstrated the presence of volatile self-inhibitor in P.graminis. However, Yarwood (1956), Wilson (1958) and Bhowmik and Prasada (1963) found evidence against its gaseous nature.

Table XVI shows that the development of crown rust was supressed when leaf pieces infected with P.coronata avenae, P.graminis avenae, P.graminis tritici and P.recondita were attached; whereas attaching the leaf pieces infected with P.striiformis, P.sorghi and P.hordei did not bring about any marked change in infection. Attaching the healthy leaf pieces to the inoculated leaves also did not bring about any reduction in infection.

It is clear from table XVII that when leaf pieces infected with P.coronata avenae were attached to cereals infected with the respective rusts, reduction in pustule development occurred on oat infected with P.graminis avenae, wheat with P.graminis tritici and P.recondita, and barley with P.hordei. There was not appreciable reduction on the development of P.striiformis on wheat and P.sorghi on maize.

It is intresting to note that when leaf piece infected with crown rust were attached to seedlings inoculated with P.hordei, the development of P.hordei was suppressed, but reverse was not true. Similar trend was observed when oat leaf pieces infected with crown rust were attached to wheat leaves inoculated with P.striiformis, but to a lesser degree.

Table XVI: Results showing the development of crown rust on freshly inoculated oat seedlings after healthy and rusted leaf pieces of certain rusts were attached.

Leaf pieces infected with	Rust infection[1] (%)		
	Infected leaf piece attached	Healthy leaf piece attached	Leaf piece not attached
P. coronata avenae	15	90	100
P. graminis avenae	20	92	100
P. graminis tritici	18	85	100
P. recondita	27	95	100
P. striiformis	75	90	100
P. sorghi	82	95	100
E. hordei	90	95	100

1 Percentage of infection was calculated on the basis of number of pustules developed on one sq.cm. on the control has been regarded as 100 per cent.

Table XVII: Effect of attaching crown rust infected leaf pieces to seedlings of certain cereals inoculated with their ropective ruste.

Leaf piece attached	P.coronate avenae	P.graminis avenae	P.graminis tritici	P.recondite	P.striiformis	P.sorghi	P.hordei
Infected	15	25	25	15	50	92	18
Healthy	97	93	95	95	90	95	89
Not attached	100	100	100	100	100	100	100

Protection by Cross Inoculation

Yarwood (1954,1956) provided evidence of antagonism in cereal rusts. Excepting the only report by Johnston and Huffman (1958) little effort has been made towards this interesting phenomenon in the case of cereal rusts.

It is clear from table XVIII that when the leaves were inoculated with P.horaei followed by crown rust, the rust development was normal at all the intervals; with P.striiformis only at first two intervals; with P.recondita and P.graminis tritici normal development of rust took place only when they were inoculated immediately with crown rust, at other intervals however, there were some reduction in the development of crown rust. On the other hand,when the inoculations with P.graminis avenae followed [illegible] inoculations with crown rust [illegible], reduction in the development of the latter took place to varying degrees.

The rust development was markedly reduced when inoculations were made with P.graminis avenae, P.graminis tritici and P.recondita followed by crown rust 7 days after inoculations with the formers.

Table XVIII: Response* of young leaves of Victory oat to infection by crown rust that were earlier inoculated with certain other rusts.

Intervals	P.graminis tritici	P.graminis avenae	P.recondita	P.striiformis	P.hordei	Control
Immediately	100	50	100	100	100	100
2½ days	35	40	40	100	100	100
5 days	25	20	30	80	100	100
7 days	3.6	5	9	50	100	100

* Development of 24 pustule per sq. cm of leaf area on the control is regarded as 100%infection.

by Fungicides

Although several attempts for the control of cereal rusts by fungicides have been made in the past, Bolley (1891), Kellerman (1891), Pammel (1892,1894), Hitchcock and Carleton (1893), Galloway (1893), Greaney (1928,1934). However, the uses were abandoned as emphasis was shifted to the use of resistant varieties. There have been again strong evidence of intrest in the subject, Mc Callan (1956), Hasket and Johnston (1958), Dickson (1959), George (1964) and Hobbs and Futrell (1966). Recently Simons and Michel (1967) used several chemicals for the control of oat rusts.

It is clear from table XIX that there was little or moderate inhibition of uredospores germination at 0.01, 0.02, 0.05 and 0.1 concentrations; high inhibition at 0.2 for Dithane S-31, RH 539 and in Dithane M-45. There was complete inhibition of uredospores germination at 0.5 per cent concentration of the three chemicals.

Fig.5 shows the efficacy of 0.2 per cent Dithane S-31, Dithane M-45 and RH 539 in controlling the crown rust infection when applied immediately after inoculations. The rust development was arrested considerably by Dithane M-45, as there was only 4 per cent of infection; whereas in case of Dithane S-31 and RH 539 it was 40 and 30 per cent respectively.

Table XIX: Percentage germination of crown rust uredospores in different concentration of the fungicides.

Fungicides	Concentration(%)					
	0.01	0.02	0.05	0.1	0.2	0.5
Dithane S-31	58.2	56.0	24.3	15.0	7.0	0.0
Dithane M-45	52.0	52.0	18.0	4.8	0.0	0.0
RH 539	52.5	51.0	20.6	11.0	3.8	0.0

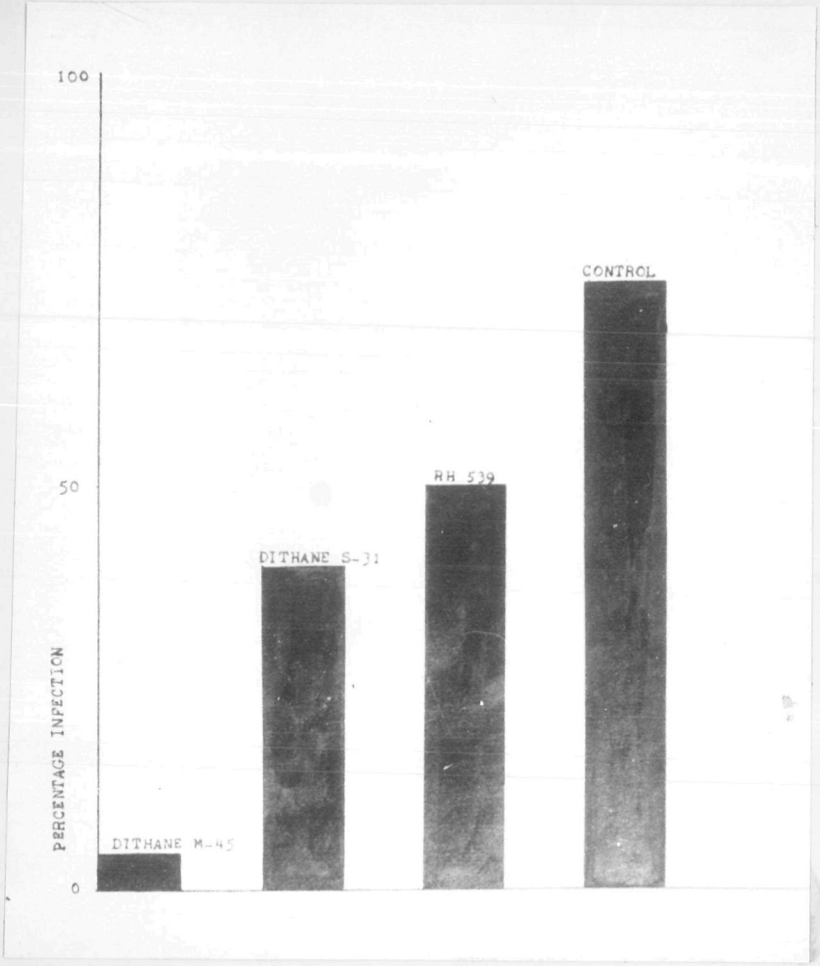

Fig.5: Percentage of crown rust infection after the applications of 0.2 per cent Dithane M-45, Dithane S-31 and RH 539.

Breeding for Resistance

The most effective means of controlling the crown rust has been the development of resistant varieties. Murphy, Stanton and Stevens (1937), Westman (1942), Osler (1951), Osler and Hayes (1953), Simons (1956), Simons et al. (1959), Sadanaga and Simons (1960), Mc Kenzie (1961), Mc Kenzie and Fleishmann (1964) worked out gene or genes for resistance in oats and their mode of inheritance. In India little attempts have been made to breed varieties of oats resistant to crown rust.

The following crosses were made with the aim in view that it might result into a promising combination:-

Landhafer x Punjab local,
ag 331 x Punjab local,
Gopher x Curt,
Gopher x VIII-578.

It is clear from teble XX that variety Landhafer possesses a single dominant gene for resistance to race 227 of crown rust, as the F_2 population seggregated into 3R : 1S. Out of 96 resistant families selected in the F_2 on testing in F_3, 81 families were found homozygous and 15 heterozygous. The latter on testing in F_4 again seggregated into 3R : 1S. Selection were made from homozygous resistant families and these were found to breed true in F_4.

Table XX: Reaction of parents, F_2, F_3 and F_4 progenies of Landhafer x Punjab local to race 227 of crown rust.

Parents and Progenies	Total No. of plants	Plants showing resistance	Plants showing susceptibility	Probable ratio	X^2	P
Landhafer (resistant) x Punjab local (susceptible)						
F_1	12	12				
F_2	140	104	36	3:1	0.05	.90-.80
F_2 selected resistant families						
F_3 families 1-81	7887	7867	--			
families 82-96	1465	1106	359	3:1	0.13	.80-.70
F_3 selected resistant families						
F_4 families 1-14	832	832	--			

It is evident from table XXI that in F_2 the segregation was 9R : 3S, thereby indicating that two complementary dominant genes were present in ag 331 against race 227. Out of 82 resistant families on testing in F_3, 9 were homozygously resistant and the remaining segregated into 3R. : 1S. The selected 9 resistant families on testing in F_4, two were found heterozygous whereas the remaining were homozygous. Thirty resistant families thus selected, breed true in F_5. Single plant selection from these families were made and were grown together with Punjab local Fig. 6 to note the performance in the field and also for further studies.

It is clear from table XXII that Copher has one dominant gene for resistance to race 227 of crown rust, the expression of which is suppressed by inhibitory factor II (IIRR). The variety Curt possessed the recessive alleles of the dominant factor present in Copher (iirr). The F_1 showed susceptible reaction due to the presence of dominant inhibitory factor received from Copher. The F_2 population segregated as 13S : 3R. The F_3 were homozygous and heterozygous resistant, the segregation of heterozygous families have been 3R : 1S, and the selected families from the homozygous type of resistant on testing in F_4 breed true. The selected single plants raised from these families have been named as GC-8 (Fig. 7). A comparison of the vegetative characters such as panicle of this strain was made with Punjab local and Kent (promising vars. for the country) Fig.8.

Table XXI: Reactions of parents, F_1, F_2, F_3, F_4 and F_5 progenies of cross ag 331 x Punjab local to race 227 of crown rust.

Parents and Progenies	Total No. of plants	Plants showing resistance	Plants showing susceptibility	Probable ratio	X^2	P
ag 331 (resistant) x Punjab local (susceptible)						
F_1	5	5	0	-		
F_2	146	82	64	9:7	0.03	.99-.98
F_2 resistant families						
F_3 families 1-9	1024	1024	0	-		
families 10-82	15640	11705	3935	3:1	0.15	.80-.70
F_3 resistant families						
F_4 families 1-6	890	890		-		
families 7-9	415	314	101	3:1		
F_4 resistant families						
F_5 families 1-31	634	634	0	-		

Fig.6: Field performance of Punjab local (L.) and the hybrid of cross between ag 331 x Punjab local (R.).

Table XXII: Reactions of parents, F_1, F_2, F_3 and F_4 progenies of cross Gopher x Curt to race 227 of crown rust.

Parents and Progenies	Total No. of plants	Plants showing resistance	Plants showing susceptibility	Probable ratio	X^2	P
Gopher (susceptible) x Curt (susceptible)						
F_1	10	0	10			
F_2	190	34	156	13:3	0.82	.50-.30
F_2 resistant families						
F_3						
families 1-46	8855	8855	0			
families 47-80	15640	3950	11665	3:1	0.67	.50-.30
F_3 resistant families						
F_4						
families 1-23	3831	3831	0	-		

Fig.7: Result showing the vegetative characters of cross between Gopher(L.) x Curt(R.) with their hybrid in the centre.

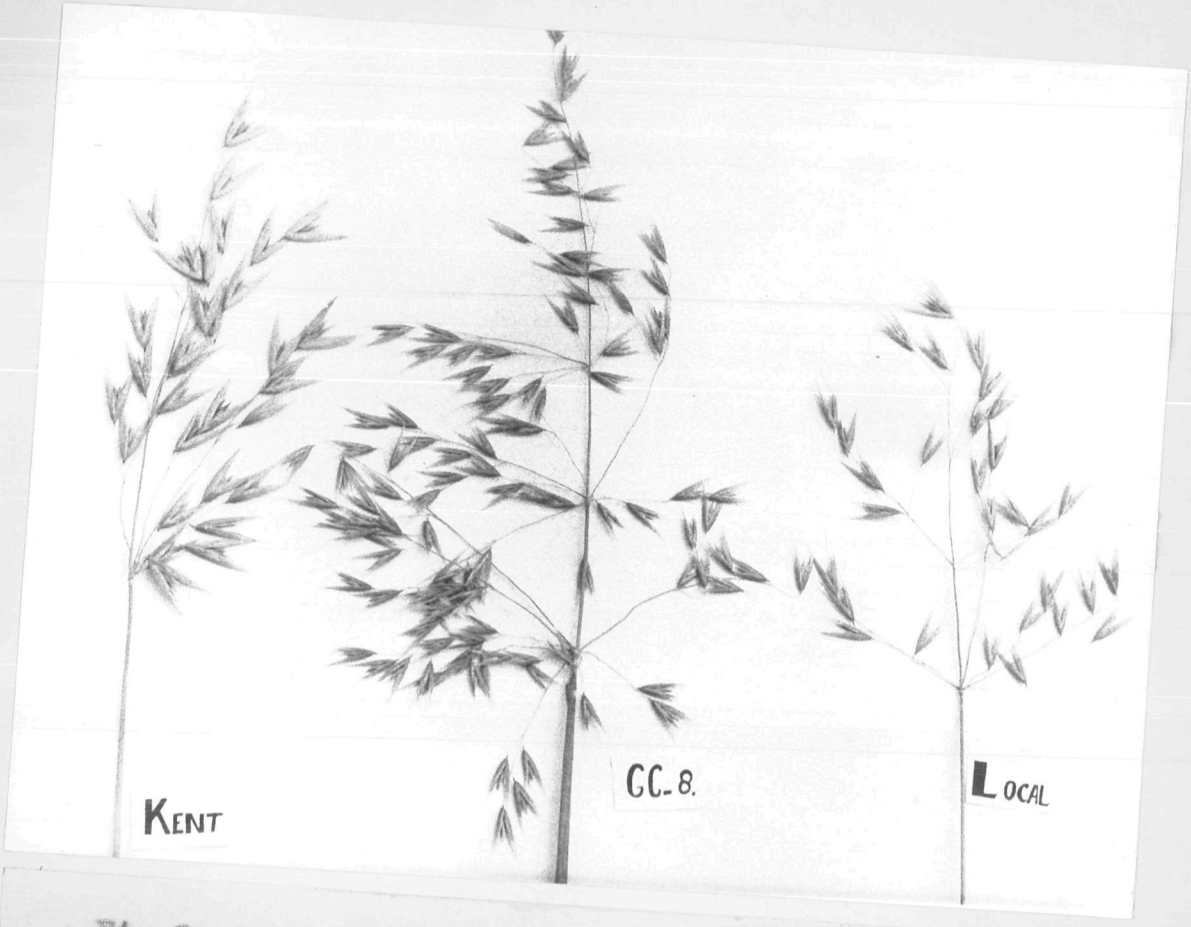

Fig.8: Comparision of panicles of Kent(L.),CC-8 (centre) and Punjab local (R.).

Table XXIII clearly shows that susceptibilit-y was dominent in F_1 . The F_2 population segregated into 3S : 1R indicating thereby that VIII-578 carried a dominant gene for resistant to race 227 of crown rust. The results further confirm that Gopher possesses a dominent inhibitory gene in addition to gene for resistance.

The strains so selected viz. LH-1 and GC-8 were latter crossed with promising varieties. The following crosses were made:-

LH-1 x GC-8,
LH-1 x Punjab local,
LH-1 x Kent,
GC-8 x Punjab local,
GC-8 x Kent,
Punjab local x Kent.

The F_1s of the above crosses were tested in the seedling stage and were allowed to grow under identical conditions (Fig. 9,10 and 11).

It is clear from table XXIV that LH-1 has a dominent gene for resistance. Similarly, F_1 seedling of crosses between GC-8 x Punjab local were resistant. It further shows that strain GC-8 does not have inhibitory gene any more; whereas the reactions on F_1s, a cross between Punjab local x Kent were susceptible indicating thereby that the two parents has dominant gene or genes for susceptibility.

It is clear from table XXV (Fig. 11) that the F_1 parents of crosses between GC-8 and Punjab local was more promising than LH-1 x Kent cross with respect to height of the plant, No.of leaves and No.of spikelets per inflorescens. The strain GC-8 showed better combining ability with other variety specially in respect to the height of plants and leaf size. There were very little differences as to the No.of tillers and the nodes Fig. 10. It is proposed to study still larger population under different conditions the combining ability of the above varieties and to their reaction to different races of the rust.

Table XXIII: Reactions of parents, F_1 and F_2 progenies of cross Gopher x VIII-578 to race 227 of crown rust.

Parents and Progenies	Total No. of plants	Plants showing resistance	Plants showing susceptibility	Probable ratio	χ^2	P
Gopher (susceptible) x VIII-578 (resistant)						
F_1	21	0	21	-		
F_2	236	46	190	3:1	3.75	.10-.05

Table XXIV: Seedling reaction of the parents and F_1s of six crosses to race 227 of crown rust.

Crosses	Reaction of the parents	Reaction of the F_1s
LH-1	R	
x		R
GC-8	R	
LH-1	R	
x		R
Punjab local	S	
LH-1	R	
x		R
Kent	S	
GC-8	R	
x		R
Punjab local	S	
GC-8	R	
x		R
Kent	R	
Punjab local	S	
x		S
Kent	S	

Fig.9: F_1 result showing the vegetative characters of cross between Punjab local(L.) and LH-1(R.).

Fig. 10: F_1 result showing the vegetative characters of cross between Punjab local(R.) and Kent(L.).

Fig.11: F_1 result showing the vegetative characters of cross between Punjab local(L.) and GC-8(R.).

Table XXV: Comparative vegetative characters of parents and their F_1 progenies studied under glasshouse.

Parents and progenies	Height (inches)	No.of tillers	No.of leaves	Length and width of biggest leaf (inches)	No.of nodes	No.of spikelets per inflorescence
Punjab local	33	3	4	17 x 0.4	4	23
Kent	28	9	3	12 x 0.3	3	18
LH-1	27	8	4	11 x 0.4	3	19
GC-8	41	8	4	17 x 0.6	4	60
LH-1 x GC-8	37.5	7	4	17 x 0.4	4	26
LH-1 x Punjablocal	49	8	5	17 x 0.5	4	19
LH-1 x Kent	27	7	3	11 x 0.3	4	21
GC-8xPunjab local	31.4	6	4	16 x 0.4	4	25
GC-8 x Kent	25	8	4	14 x 0.4	4	22
Punjab local x Kent	31	6	3	10 x 0.4	4	13

DISCUSSION

Puccinia coronata avenae is one of the most important rusts of oats and is found in almost all the oat growing areas of the world (Dickson (1956). In India it is confined to northern region and so far only three races have been reported, whereas in the U.S.A. more than 35, in Australia 30 and in Europe 25 races have been reported. Very little is known about the different aspects of this rust under Indian conditions. In India crown rust epidemic occurred in 1909 (Butler and Bisby, 1931), however, sporadic out-break of this rust are not un-common.

In the present studies it was observed that there was complete inhibition in the 5/2 concentration of leaf extracts of Thalictrum javranicum, T.reniforme, Cannibis sativa, Daturastra stramonium, Eucalyptus sp., Oxalis corniculata, O.acetocella, Rumex nepalensis, R.hastatus, Urtica dioica, U.parviflora, Girandinia heterophylla, Germium sp., G.lucidum, G.divaricatum G.nepalense, Rhamnus purpureus, R.virgatus, Viola canescens, Vitis himalayana, V.parviflora, Impatience balsamina, Berberis aristata, B.lycium. Papaver sp. was an exception where the percentage germination of uredospores was almost the same as in water. These findings are in agreement with those of Hirata (1962) who also found considerable inhibition in filtrate of fungi, and Kono (1962) who found inhibition of uredospores germination in saps of hosts and non-hosts plants.

There are contrary reports as to the factors which induce the formation and germination of teliospores of P.coronata avenae. According to Peturson (1930) and Simons (1954) telia were produced at moderate temperatures more rapidly than at low temperatures. Magnus (1891) and Gassner (1915) suggested that host vigour and physiologic aging were conducive for the development of telia. In the present studies it was found that telia were produced more or less abundantly between 22-28°c irrespective of the age and the reaction of the host

to the rust. Thus confirming the findings of Peturson (1930) and Simons (1954).

Freshly formed telia failed to germinate despite subjecting them to various treatments both physical and chemical; whereas telia that were allowed to overwinter under natural conditions germinated. Thus confirming the observations of Noerner (1921,1922) and Zimmer, Schafer and Gries (1961).

Out of 134 grasses tested, rust developed only on Avena elatior, A.fetua, A.glauca, A.sativa, A.strigosa, Helictotrichon asperum, H.versesconse, Hordeum distichon, H.irregulare, H.murinum, Muhlenbergia huegelii, Phalaris arundinacea, P.canariensis, P.minor, Vulpia myuros. It is interesting to note that, A.sativa, Phalaris arundinacea, P.minor and Muhlenbergia huegelii are widely prevalent in northern hilly areas where the rust is invariably found. These grasses may therefore, function as collateral hosts in the perpetuation of the rust from year to year.

There were several reports of the losses to oats due to crown rust from U.S.A. and Europe. The losses were found to be 90 per cent when the infection was initiated at the seedling stage followed by repeated inoculations (4-5 times) in the glasshouse, the losses were reduced or were negligible when the infection was initiated at the boot or flag-leaf stage, thus confirming the observations of Murphy (1935). In the field test when artificial epidemic was created on Punjab local and Kent, the losses had been 40 and 50 per cent respectively. The low incidence of the rust on the inoculated plants could be attributed to the fact that inoculation at the mid-age or late age of the plants resulted in production of the limited cycles of the rust, on the other hand when the seedlings were inoculated the rust had ample opportunity to produce several cycles. Thus confirming the reports of Pammel (1907), Corkle and Mehlus (1941) and Sherf et.al. (1954).

An attempt to ascertain the number of races present in Himachal Pradesh, Punjab and Uttar Pradesh revealed that only races 227, 231 and 240 were present. The prevalence and distribution of these races however, differed in different states and in different years under study. This uniformity could partly be explained as in all the three states varieties having common germ plasm are grown.

An isolate was obtained in 1966-67 which differed in its reaction on the differentials. A detailed study of this isolate revealed that it did not only differ from the races reported from India and that it resembled to some extent with races 261 and 344, Simons and Michel (1964), but actually differ from the former in its pathogenicity on Ukrain and Landhofer, from the latter on Ukrain and Santa Fe. This isolate therefore, is new and has been tentatively designated as race 8. During 1966-67 new race 8 comprised only a fraction of the races, however, in the following year, 1967-68, the population of race 8 was second to none.

The experiment on mutation revealed that genes controlling the pathogenic reaction of race 227 can be induced by mutagenic treatment. As a result of Ultraviolet exposures for 30,40,50 and 60 minutes to the uredospores of the race 227 brought about increase in pathogenicity of the race. Further exposures upto 100 minutes increase the pathogenicity of the race. The races obtained as a result of exposure to UV do not exist in India or elsewhere. These findings are in agreement with those of Griffiths and Carr(1961).

Out of 139 out vars. screened against individual races 227, 231, 240 and 8 only vars. Trispernia, Victoria, Bond, Overland, VIII-578 and ag 351 were found to be resistant to all the races. Trispernia, Victoria and Bond are included in the differentials for crown rust and so far these vars. remain resistant to the new races that are picked up from the country, they can as such serve as resistant donors.

Many oat investigators believe that disease resistant varieties can be maintained only by continuous breeding to keep pace with the incontrollable change in races of highly specialised P.coronata avenae, Coch et al. (1945), Litzenberger (1949), Leetman (1942). As a result of these investigations the genes governing resistance in the differential vars. Victoria, Santa Fe, Landhafer, Ukrain, Crispernia and Bond have been worked out, Finkner (1954), Simons and Murphy (1954), Simons, Sadanaga and Murphy (1959), Sadanaga and Simons (1960). Resistant Oat vars. ag 331, Landhafer, VIII-578 were used to incorporate resistant gene/genes into the promising varieties. Crosses were made between Landhafer x Punjab local; VIII-578 x Gopher; ag 331 x Punjab local besides a cross between susceptible Gopher x susceptible Curt. It was found that Landhafer possesses a single dominant gene for resistance to race 227 of crwn rust confirming the earlier report, Murphy, Stanton and Stevens (1937), Leetman (1942), Coch et al (1945), Litzenberger (1949); ag 331 has got two complimentary factor pairs, it has also been found to carry genes Ad for stem rust (through personal communication from Dr.D.J.Stewart, Prof. Plant Pathology, University of Minnesota, U.S.A.). The result of cross between Gopher x Curt showed that Gopher has one dominant gene for resistance and the expression of which was supressed by another inhibitory gene; whereas var. VIII-578 also carries one dominant gene for resistance. Resistant cultures were selected from the fixed families of cross Landhafer x Punjab local; Gopher x Curt and were named as LH-1 and GC-8, respectively. These cultures were used to prepare diallele crosses with Punjab local and Kent. The F_1s were found to be resistant where LH-1 and GC-8 were used, confirming that these parents have dominant gene or genes in them, on the other hand, when susceptible Punjab local was crossed with susceptible Kent the F_1s were susceptible, indicating thereby that these parents have dominant gene or genes for susceptibility. Moreover, agronomically speaking the cultures LH-1 and GC-8 were as good as other Indian promising varieties.

SUMMARY

The uredospores of Puccinia coronata avenae was completely inhibited in the 5/2 dilution of the leaf extracts of Thalictrum javanicum, T.reniforme, Cannabis sativa, Datura stramonium, Eucalyptus sp., Oxalis corniculata, O.ocetocella, Rumex nepalensis, R.hastatus, Urtica dioica, U.parviflora, Girardinia heterophylla, G.nepalense, Rhamnus purpureus, R.virgatus, Vitis himalayana, V.parviflora, Impatience balsamina Berberis aristata, R.lycium except in Papayer sp., leaf extract.

The teliospores of the three races of the rust were formed on the seedling and adult plants of susceptible as well as resistant varieties of oats at 18-22°c. and 22-28° c. Freshly formed telia could not be made to germinated by the alternate freezing and thawing or wetting and drying. Similarly treating teliospores with chemicals do not initiate the germination, on the other hand teliospores naturally overwintered germinated readily.

Rust developed only on Avena elatior, A.fetua, A.glauca A.glauca, Helictotrichon asperum, H.virescens, Hordeum distichon, H.murinum, H.irregulare, Muhlenbergia huegelii, Phalaris arundinacea, P.canariensis, P.minor and Vulpia myuros.

In glasshouse tests losses in yield of both Kent and Punjab local were high when inoculated at the seedling stage followed by repeated inoculations, however, losses were moderate when plants were inoculated at boot stage and negligible at flag leaf stage. Similar results were obtained under field conditions but net losses were relatively low.

During the entire period of study (1964-65 to 1967-68) only races 227 and 231 were found in Himachal Pradesh, while in the Punjab in addition race 240 was also isolated, in Utter Pradesh the same races were present as in Punjab,however, during 1966-67 a new culture was obtained, and was arbitarily named as race S. In 1967-68 it became the most predominant race in Uttar Pradesh.

Experiments on induced mutation in race 227 of the fungus revealed that the gene controlling the pathogenicity was altered by varying degrees of exposure to Ultraviolet rays; exposure to UV for 80 to 100 minutes brought about maximum change in pathogenicity of the test race. Mostly changes have been towards increase pathogenicity.

Of the 134 oat varieties screened against races 227 231, 240 and S only vars. Trispermia, Bond, Overland, VIII-578 and ag 331 were found to be resistant to all these races.

The development of crown rust was inhibited when leaf pieces infected with crown or stem rust, wheat leaf pieces infected with stem or leaf or stripe rust and barley leaf pieces infected with leaf rust were attached.

The crown rust development were also arrested by cross inoculation with oat stem rust, stem and leaf rust of wheat and not by stripe rust and leaf rust of barley.

Studies on the control of the rust showed that the fungus can be controlled considerably by 0.2 per cent Dithane M-45 as foliar spray. Dithane M-31 and RH 559 also reduce the rust development to some extent when applied in similar fashion.

Culture from fixed families of the crosses Landhafer, x Punjab local, and Gopher x Curt, showing resistance to race 227 named arbitarily as LH-1 and GC-8 respectively were used to prepare diallele crosses with Punjab local and Kent. The F_1 plants of such crosses were found to be resistant.

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* Original not seen.

APPENDIX

Some of the reprints of the author's published work cited in the thesis are attached.

A POSSIBLE CONTROL OF WHEAT RUSTS THROUGH HYPERPARASITE.

S.T.Ahmad

Experiments were under taken to study the effect of the Trichothecium roseum Link. extract in the control of wheat rusts. Pure culture of the hyperparasite (T.roseum) was prepared by isolating the fungus from the uredopustules of brown rust. Germination of the uredospores of Puccinia graminis tritici (Pers.) Erikss. and Henn., P.recondita Rob. ex Desm. and P.striiformis West. were observed to be inhibited by a 25 per cent extract of the fungus. In them subsequent studies filtrate of the fungus was sprayed on Agra local wheat seedlings previously inoculated with P.g.tritici at the time of flecking, appearance and maturation of the rust. It was observed in first two cases that the development of the rust was considerably supressed as compared to the control. Similar results were obtained in case of P.recondita.

In another experiment an unfolded seedlings of wheat were grown in the concentrated solution of the fungus extract. These were inoculated with P.g.tritici and P.recondita separately, with control grown in water. It was observed that in both the cases resistant types of rust pustiles appreared, whereas showed usual susceptible type of infection with more number of pustules per leaf.

It is therefore, appears possible that some suitable product can be derived from the fungus to control the wheat rusts more economically.

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(9)

PERFORMANCE OF OAT VARIETIES AGAINST PUCCINIA CORONATA AVENAE AND PUCCINIA GRAMINIS AVENAE

D. P. MISRA, SHEODHAN SINGH AND S. T. AHMAD

(Accepted for publication May 6, 1965)

Oat is a minor fodder crop in India. Recently varieties like Kent, Overland, Curt, White Algerian have been introduced by the Division of Plant Introduction, Indian Agricultural Research Institute, New Delhi and are being tried for the purposes of breakfast cereals and fodder. The performance of some of these have been observed to be considerably superior to the indigenous varieties in field. In many countries either or both the rusts viz., *Puccinia coronata avenae* (crown rust) and *P. graminis avenae* (black rust) have been known to cause considerable losses to oat crop. In India, black rust of oat has been found to be prevalent only in Nilgiri Hills and 4 races have been identified by Mehta (1940). From North India, Payak and Misra (1963) and Misra *et al.* (1964) have identified 3 races of crown rust. In view of the increasing importance now being given to the cultivation of oats in the country, it was considered necessary to have information on the performance of available oat varieties against the two rusts. This might enable the release of suitable varieties of oat as also to embark upon programme of breeding resistant varieties, if necessary. In the present paper, the results of 88 varieties (exotic and Indian) of oats, tested in the seedling stage against the rust material so far met within the country, are reported.

RESULTS : Oat varieties were tested with races 227, 231 and 240 of crown rust individually and with a mixture of races 3, 4, 6 and 7 of black rust. The races of black rust were isolated about three decades ago and the existing seed of differentials was not found reliable for determining the purity of these races and therefore, the races were used in mixture for testing.

Out of 88* varieties thus tested, the following 57 varieties were found to be susceptible to all the races of the two rusts :

N. P. 1, Hyb. 1, Hyb. 2, Hyb. 3, Hyb. 4, Junagarh Farm 1, Junagarh Farm 2, Kanpur local, Layallpur local, I-251-32, II-97-84, II-51-9, III-242-56, IV-B-16-17, X-27, XI-A-24-30, XI-A-325-16, XII-B-93-51, XIII-B-116-36, XIII-B-116-36G, XIII-B-153-2, XIV-76-55, XV-75-73, XV-75-73G, B. S. 1, B. S. 2, B. S. 4, P. F. 2, Reed 12, Reed 14,

*18 out of 88 varieties were tested against crown rust races by Misra *et al.* (1964) and here in these varieties have been tested with *P. g. avenae*. However, the results have been consolidated in this paper for convenience.

TABLE : Comparative reactions of 31 oat varieties with races of crown rust and black rust of oat.

Oat Varieties	*Puccinia coronata avenae* Races			*P. g. avenae* Races 3, 4, 6 and 7 (Mix).
	227	231	240	
1. I-80-40	I—S	I—S	I	S
2. VII-265	I—S	I—S	I	S
3. VIII-578	R	R	R	S
4. Iowa-103	I—S	R—I	R	S
5. Iowa-670	S	I—R	R	R
6. Budha	I—S	R—I	R	S
7. Gopher	S	S	R	R
8. Kandula	I—S	I—S	S	R
9. Markton	S	S	I—R	R
10. Mulga	I—S	R	R	S
11. Norton	S	S	R	S
12. Reed 10	S	S	R	S
13. Algeria	I—S	R—I	R	S
14. Angnoise	I	R—I	R	S
15. Breenker	I—S	I	R	S
16. Fulgum	S	I—S	R	S
17. Gidque	S	S	R	S
18. Overland	R	R	R	S
19. White Algerian	S	S	I	S
20. X-27	I	I	I	S
21. New Australian	I	R	I	S
22. Curt	S	S	S	R
23. Bondvick	R	R	R	SR
24. Ukrain	S	S	R	S
25. Landhafer	R	R	R	S
26. Bond	R	R	R	S
27. Saia	S	R	R	R
28. Appler	S	R	R	S
29. Santa Fe	I	R	R	SR
30. Trispernia	R	R	R	SR
31. Victoria	R	R	R	S

N. B.—S—Susceptible ; I or SR—Intermediate or mixed type ; R—Resistant.

Sr. No. 1 to 17—seed received from Botanical Sub-Station, Indian Agricultural Research Institute, Pusa.

Sr. No. 18 to 22—seed received from Division of Plant Introduction, Indian Agricultural Research Institute, New Delhi.

Sr. No. 23 to 31—Differentials of crown rust of oat.

Reed 19, Reed 19A, Reed 21, Reed 22, Reed 23, Reed 29, Iowa 105, Abundance, Advocated, Carston, Knota, Laggoon, Neb. 21, Palestine, S. Potato (seed received from Botanical sub-station, Indian Agricultural Research Institute, Pusa) ; Boris opus, Kent, Adliker, Dale, Ballidue Avon, Fleming Gold (seed received from Division of Plant Introduction, Indian Agricultural Research Institute, New Delhi) ; Richland, Jonette, Minrus, Victory, Anthony.

Remaining 31 varieties showed different reactions to the material of rusts and their comparative reactions are set out in the table.

It is seen from the table that no single variety is resistant to all the races of the two rusts. Varieties VIII-578, Overland, Bondwick, Landhafer, Bond, Trispernia, and Victoria are resistant to crown rust races and Iowa 670, Gopher, Kandula, Markton, Curt, Saia, are resistant to black rust of oat.

CONCLUSION : In India, limited studies have been undertaken so far for determining the prevalence and distribution of races of crown rust and black rust of oat, and therefore, more races are likely to be found on comprehensive study. However, with the known races, 88 varieties of oat were tested and most of them have been found to be susceptible to races of both the rusts and remaining varieties were resistant to one or more races.

Bondwick, Trispernia, Landhafer, Victoria and Bond have been found to be resistant to the three races of crown rust and these varieties are already included in the set of differentials for crown rust races. As long as these varieties remain resistant to the new races that are picked up in the country, their derivatives are likely to be of promise against this rust. Landhafer and Victoria in U. S. A. are found to carry one gene in each for resistance to crown rust and Bond with two complementary factors for resistance (Litzenberger, 1949). These varieties are known to be good parents as donors for disease resistance but are not commonly cultivated (Stanton, 1955). However, Overland which has also been found resistant to the 3 Indian races of crown rust (227, 231, 240), is being cultivated in the states of Idaho, Montana, Oregon, Utah and Washington in U. S. A. (Stanton, 1955). Therefore, in North India where black rust of oat is not reported to occur, it may be worth while testing the suitability of Overland for cultivation.

Gopher, Markton, Iowa 670, Kandula, Curt and Saia have been found to be resistant to black rust of oat. Out of these, Gopher and Markton are under cultivation in a number of states in U. S. A. (Stanton, 1955). Therefore, in the penninsular India, where black rust is common and crown rust is not reported, these varieties may be taken for extensive yield trials. However, all the aforesaid six varieties may be of utility as donors for black rust resistance.

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(8)

A RUST ON HELICTOTRICHON ALTERNATING WITH THALICTRUM

D. P. MISRA*, S T. AHMAD AND SHEODHAN SINGH

(Accepted for publication July 4, 1968)

During the mycological surveys in Simla hills, a rust on *Helictotrichon virescens* (Nees. ex Steud) Hern. was collected. The uredia of this rust were paraphysate ; telia were devoid of mesospores and the teliospores were without crown These characters differentiated this from the two rusts described on species of *Helictotrichon* viz *Puccinia helictotrichoni* Jorst in China and *P coronata* Corda in India (Jorstad, 1959, Payak and Misra, 1963) This rust was morphologically identical to *P recondita* Rob ex Desm , and has not been recorded so far on the said host *Thalictrum javanicum* Blume with aecial infection was observed during rainy season in close proximity, where *H. virescens* with the said rust infection was found in the following months Keeping in view these observations, it was considered desirable to work out the life cycle and systematic position of this rust. The present paper deals with the findings pertaining to these aspects.

MATERIAL AND METHODS Uredial and telial stages of the rust were collected during September to December, 1964 at Simla (2,200 m. a.s l) Uredial infection was established on the seedlings of *H. virescens* raised from seed in glasshouse Later, the telia also developed on these seedlings The telial material thus obtained was frozen in tap water for 10 days. After thawing, the material was processed for germination by alternate wetting (4-7°C) and drying (8-10°C) for two days in each case Prior to each drying, a portion of telial material was teased on a microscope slide and kept for germination in tap water (12-18°C). The teliospore germination was observed after two wettings

Seeds of *H. virescens* and *T javanicum* were collected from field and the plants from these were used for inoculations under glasshouse conditions to ward off contaminations.

RESULTS Considering the circumstantial evidence, that *T. javanicum* with aecial infection and *H virescens* with uredial and telial infections (similar to *Puccinia recondita*) grew in close proximity, it was intended to explore the possible genetic relationship of the infections on the two hosts Therefore, germinating teliospores were inoculated on young leaves and shoots of *T. javanicum*. Inoculated plants were sprayed with tap water and kept in humid chamber for two days at 15-20°C and then transferred onto glasshouse bench. Pycnia started appearing after 8-10 days, followed by aecia in the next 8 days. Aeciospores were collected from these and inoculated on young seedlings of *H. virescens*. Uredia developed within 15-18 days at 15-22°C followed by telia in due course The uredia and telia were re-examined. The characters were found to be the same as those of the stages collected on *H virescens* in

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nature. Thus, it was established that the rust on *H. virescens* was eu-type and heteroecious with *T. javanicum* as its alternate host.

In order to study the host range of the rust some more hosts of Graminae were tested in seedling stage against uredospores and aeciospores. These included *Agropyron elogatum* (Host.) Beauv., E.C. 17894 : *A. semicostatum* (Steud.) Nees.; *Avena byzantina* C. Koch.; *Festuca* I.W. 1850; *F. gigantia* (L.) Vill.; *Hordeum vulgare* L. var. *Agra local : Lolium perenne* L. and *Triticum aestivum* var. *Agra local.* None of these got infected indicating that this rust is specialised on *Helictotrichon* and is different from the rusts known to parasitise the said hosts.

Morphological studies of the uredial and telial stages of the rust under reference, revealed that the characters agree with the description of *Puccinia recondita* (Cummins, 1965; Jorstad, 1962), except for its paraphysate uredia. Aecial material broadly agreed with the description of *Aecidium Thalictri-Flavi* on *T. javanicum* recorded at Urni (200 kms. North of Simla) by Barclay (1887).

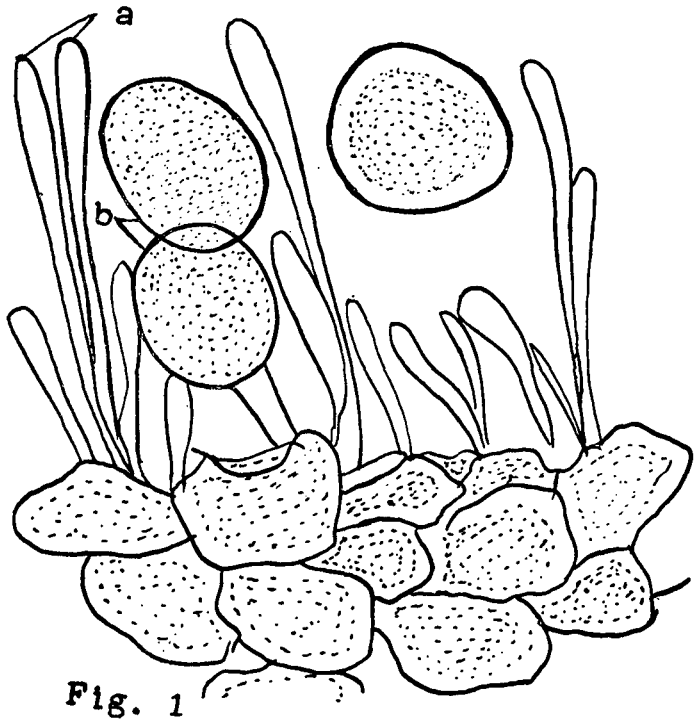

Fig. 1. Uredosorus : a. paraphyses ; b. uredospores

In view of these facts, the rust on *H. virescens* is being named as *P. recondita* and *A. Thalicti-Flavi* is being considered synonym representing the aecial stage of the rust. However, it desreves the status of a new variety of *P. recondita* because of its restricted parasitising nature

on *H. virescens* and paraphysate uredia. Such instances of minor structural difference and host specialisation are known in *P. recondita*, which is considered to be a complex species comprising of varieties (Jorstad, 1962). The description of the rust is being given hereunder. The material has been deposited in the *Herbarium Cryptogamae Indae Orientalis*, Indian Agricultural Research Institute, New Delhi-12.

Puccinia recondita var. *simlensis* var. *nov.*

Uredia elliptica, elongata, dispersa, primo subepidermalia, tum erumpentia, paraphysata, paraphyses plures, in soro interspersae, hyalinae, clavatae, parietibus gracilibus, 60-70 μ longae, 6-8 μ apicaliter latae; inficit *Helictotrichon virescens* et *Thalictrum javanicum*.

O, I –*Thalictrum javanicum* Blume, Simla (2,200 m. a.s.l.) H.C.I.O. No. 29160 Type.

II, III—*Helictotrichon virescens* (Nees. ex Steud.) Hern. Simla (2,200m. a.s.l.) H.C I.O. No 29161 Type.

Lectus a Misra, Ahmed et Singh ad Simla, aprile, 1965.

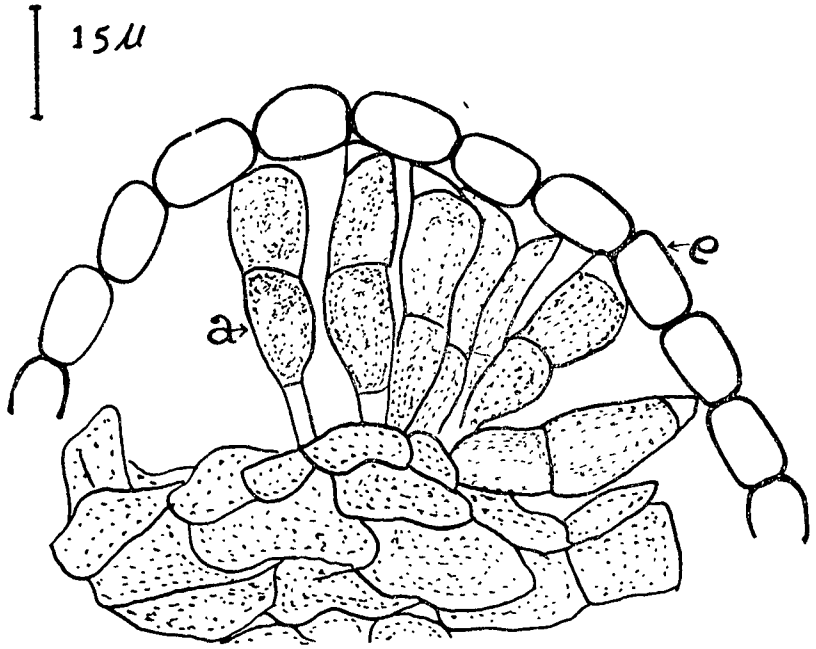

Fig. 2

Fig. 2. Teliosorus : a. teliospores ; b. epidermis

Pycnia when foliicolous, epiphyllous, occassionally on petioles and stem, sugary secretion copious. subepidermal, globose, or flask shaded, paraphysate, 100-120 μ deep and 90-100 μ wide. Aecia follicolous, hypophyllous, clustered, deep yellow. 1-2 mm. high, peridial cells

rhomboid 14-24 × 12-18 μ. Aeciospores yellowish orange, angular by ovoid echinulate 21-30×21-27 μ. Uredia erumpent dull orange, epiphyllous, occasionally caulicolous, usually foliicolous, upto 2 mm. long, longer than broad, scattered, paraphysate, Uredospores dull orange, echinulate, round to ovoid, 25-30×21-27 μ. Paraphyses numerous, hyaline, 60-70 μ long, 6-8 μ broad at the apex. Telia epiphyllous, scattered or in irregular stripes, non-erumpent, ash black, Teliospores clavate or oblong clavate, apex truncate or which oblique conical tapering, slightly constricted at the septum, tapering below, 30-39×9-15 μ. Pedicel persistent, hyaline, 6-10μ long.

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(7)

Natural occurrence of specialised forms of Puccinia graminis and P. striiformis on Lolium perenne.— D. P. MISRA, S. T. AHMAD AND SHEODHAN SINGH, Division of Mycology and Plant Pathology, Indian Agricultural Research Institute, New Delhi—*Lolium perenne* is an introduced grass in Simla hills which now grows wild.[1] During the course of surveys in and around Simla, it was found to be infected with two rusts—identy based on colour and size of uredo pustule. Morphological studies revealed that one of the rusts resembles with that of *Puccinia graminis* and the other with *P. striiformis*.

P. graminis and *P. striiformis* have been reported to comprise numerous specialised forms infecting various grasses. Some of these grasses also harbour the specialised forms of the rusts infecting cereals like wheat and oat and as such serve as collateral hosts. Different forms of *P. graminis* on *Agropyron semicostatum* and *Poa nemoralis* and of *P. striiformis* on *A. semicostatum Phalaris minor* and *Muehlenbergia hugelii* have been reported from India and it has been further established that *A. semicostatum* and *M. hugelii* function as collateral hosts of black rust and yellow rust respectively[4], [5]. Besides these, several other indegenous and exotic grasses have been reported to get infected with *P. graminis tritici*, *P. g. avenae* and *P. striiformis* in laboratory or in nature [2], [3], [5], [6], [7].

There appears to be no record of any rust on *L. perenne* in the country except that collections of this grass received from Australia and Pakistan (Quetta) when grown at Delhi during 1948-49 were found to be infected with *P. g. tritici*[6]. However, this grass has been reported to be host for both, *P. graminis* and *P. striiformis* from elsewhere but no pathological tests seem to be attempted to ascertain that the forms of these rusts are specialised on *L. perenne*.

The two rusts were maintained on the original host and their pathogenicity was studied under glasshouse conditions. It was found that the rusts are restricted to the original host, whereas eleven exotic collections of *Lolium* sp. (E. C. 16005, E. C. 16127, E. C. 16473, E. C. 16746, E. C. 16747, E. C. 16752, E. C. 16753, E. C. 16754, E. C. 18330, E. C. 18332 and E. C. 20647), eight exotic collections of *Phleum* sp. (E. C. 16734, E. C. 16738, E. C. 16739, E. C. 17946, E. C. 17947, E. C. 18333, E. C. 21246 and E. C. 21247) nine exotics of *Festuca* sp. (E. C. 15123, E. C. 16733, E. C. 16741, E. C. 16745, E. C. 19749, E. C. 17037, E. C. 17948, E. C. 18329 and E. C. 18342) two indegenous *Festuca* spp. (I. W. 1849 and I. W. 1850), exotic *Avena elatior* (E. C. 18339) indeginous *Agropyron semicostatum, Helictotrichon virens, Poa nepalensis, Muehlenbergia hugelii, Triticum aestivum* (var. Agra local) and *Hordeum vulgare* (var. Agra local) did not get infected. On the other hand the plants of *Lolium perenne* from Simla were found to be immune to the races of *P. graminis tritici* and *P. striiformis* of wheat, in separate mixtures.

In the light of this, it is concluded that the rusts herein reported are specialised forms of *Puccinia graminis* and *P. striiformis* on *Lolium perenne.*

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SPECIALIZED FORMS OF *PUCCINIA CORONATA* CDA. ON SPECIES OF *AGROSTIS* AND *FESTUCA*

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Puccinia coronata Cda. is known to infect several genera of grasses. On the basis of host specificity several *forma speciales* of rust have been reported from different countries of the world (Mühlethaler, 1911; Klebahn, 1912; Peturson, 1954). In India crown rust has been found to occur on *Poa*, *Oryzopsis* (syn. *Piptatherum*), *Agrostis*, *Brachypodium*, *Agropyron*, *Stipa* and *Helictotrichon* (including the synonym *Avenastrum*). Two specialized forms, namely *P. coronata* var. *himalensis* Barcl. emend. Payak & Misra on *Brachypodium sylvaticum* (Huds.) P. Beauv., and *P. coronata* var. *avenae* Fraser & Led. on *Avena* sp., have been shown to occur (Payak and Misra, 1963). In the present paper studies on crown rust of *Agrostis pilosula* Trin. (syn. *A. royleana* Trin.) and *Festuca gigantea* (L.) Vill. have been reported.

MATERIAL AND METHODS

Rusts on *Agrostis pilosula* and *Festuca gigantea* (uredial and telial stages) were collected from the neighbourhood of Simla. Uredial cultures were maintained separately on the seedlings of the original hosts. Telia were developed during October–November (below 22°C) on the respective hosts. Leaves and culms bearing mature telia were immersed in tap water and frozen (0° to –5° C) for 20–25 days. After thawing, these were alternately wetted (3°–7° C) and dried (8°–10° C) for 2 days. Teliospores started germination after three treatments and these were used for inoculation of *Rhamnus* plants separately. Pycnia developed in 10–12 days at 15°–22° C, followed by aecia. Mature aeciospores were tapped on butter paper and were inoculated on the healthy leaves of grasses to determine their pathogenicity.

With the uredial inoculum of rusts from *A. pilosula* and *F. gigantea*, two sets of 55 grasses representing 16 genera were tested separately. Grasses found resistant to both the rusts were *Pseudoraphis spinescens* (R. Br.) Vickery (syn. *Andropogon squarrosus* L. in Herb. L., non L. f.), *Agrostis stolonifera* L. (syn. *A. alba* auct. non L.), *A. munroana* Aitch. & Hemsl., *Arrhenatherum elatius* (L.) J. S. & C. B. Presl (accessions 'E.C. 17934', 'E.C. 1735', 'E.C. 1936'), *Avena byzantina* C. Koch, *A. strigosa* Schreb., *Brachypodium sylvaticum* (Huds.) P. Beauv., *Bromus japonicus* Thunb., *Dactylis glomerata* L., *Festuca* sp. (accessions 'E.C. 15123', 'E.C. 16741', 'E.C. 16744', 'E.C. 16745', 'E.C. 17037', 'E.C. 17949', 'E.C. 18329', 'E.C. 18342' and 'I.W. 1849'), *F. pratensis* Huds. (accessions 'E.C. 16733' and 'E.C. 17948'), *Vulpia myuros* (L.) Gmel. (syn. *F. myuros* L.), *Lolium* sp. (accessions 'E.C. 16005', 'E.C. 16127', 'E.C. 16743', 'E.C. 16746', 'E.C. 16747', 'E.C. 16752', 'E.C. 16753', 'E.C. 16754', 'E.C. 18330', 'E.C. 18332' and 'E.C. 20647'), *L. perenne* L., *Phalaris* sp. (accessions 'E.C.

15122 ', ' E.C. 15991 ' and ' E.C. 16756 '), *P. minor* Retz., *Phleum* sp. (accessions ' E.C. 16734 ', ' E.C. 16738 ', ' E.C. 16739 ', ' E.C. 17946 ', ' E.C. 17949 ' and ' E.C. 18333 '), *P. pratense* L. (accessions ' E.C. 21246 ' and ' E.C. 21247 '), *Poa annua* L. and *P. pratensis* L. (' E.C. 18047 ').

Grasses on which infection was produced by one or both the rusts are listed with infection types in Table I.

TABLE I. INFECTIVITY OF GRASSES TO RUSTS FROM *AGROSTIS PILOSULA* and *FESTUCA GIGANTEA*

Grasses	Infection types of rusts from	
	A. pilulosa	*F. gigantea*
Avena glauca L.	3	0
Agrostis pilosula L. (syn. *A. royleana*)	3–4	0
Festuca sp. ' I.W. 1850 '	0	3–4
F. gigantea (L) Vill.	0	4
Muehlenbergia hugelii Trin.	4	3–4

0=Resistant; 3-4 = Susceptible.

The rust from *A. pilosula* did not infect *F. gigantea* (L.) Vill. and *vice versa*. *Avena glauca* was susceptible to the rust from *Agrostis* sp. and resistant to that of *Festuca* sp. An indigenous collection of *Festuca* (' I.W. 1850 ') was susceptible to *Festuca* rust and resistant to the other. However, *Muehlenbergia huegelii* Trin. was susceptible to both the rusts.

Morphological characters of the stages of rusts on *A. pilosula* and *F. gigantea* and those produced on *Rhamnus purpureus* Edgw. agreed with the descriptions on *Puccinia coronata*. On critical examination, the rust on *Agrostis* could be distinguished from that on *Festuca*. Cross-inoculation tests with the aeciospores further confirmed that the two rusts are specialized on their original grass hosts. The distinctive characters of the two rusts are given in Table II.

TABLE II. MORPHOLOGICAL DIFFERENCES BETWEEN THE TWO CROWN RUSTS SPECIALIZED ON *AGROSTIS* AND *FESTUCA*

Puccinia coronata on	
Agrostis	*Festuca*
Spermagonia 100–120 μ deep	Spermagonia 80–100 μ deep
Peridial cells rhomboid or oblong, 18–24 μ × 21–30 μ	Peridial cells rhomboid and angularly oblong, 18–27 μ × 21–38 μ
Uredia minute, orbicular, in short irregular stripes; light cinnamon-brown	Uredia larger up to 1–3 mm long, scattered, shining orange
Urediospores 21–28 μ × 15–25 μ	Urediospores 19–24 μ × 16–20 μ
Paraphyses 27–50 μ long and 12–15 μ broad (at the head)	Paraphyses 90–150 μ long and 7–10 μ broad (at the head)
Teliospores 42–60 μ × 9–18 μ, average 42 μ × 13 μ (without projections)	Teliospores 35–65μ × 12–18 μ, average 48 μ × 14 μ (without projections)
Crown 6–14 μ long and projections turning laterally	Crown up to 10 μ long, projections usually vertical
Upper cells of teliospores 13–28 μ × 10–18 μ	Upper cells of teliospores 9–14 μ × 12–18 μ
Lower cells of teliospores 18–30 μ × 9–14 μ	Lower cells of teliospores 21–40 μ × 6–14 μ

FIGS 1–4 Substantiate some of the observations given in Table II.

DISCUSSION

Eriksson (1897) described several varieties of *Puccinia coronata* based on host specialization. Peturson (1949) reported *P. coronata* var. *agrostis* and further stated that on the basis of the measurements of urediospores and teliospores it closely resembles *P. coronata agrostidis* described by Eriksson (1897). Several species of *Agrostis*, viz. *A. hiemelis* Watt., *A. tenuis* Sibth., *A. lacantha* Necs., *A. nebulosa* Boiss. & Rent and *A. rupestris* Champ., were found to be infected with *P. coronata* var. *agrostis* in the studies of Peturson (1949). In the present studies *A. pilosula*, *A. stolonifera* L. (syn. *A. alba* auct. non L.) and *A. munroana* Aitch. & Hemsl. were tested with the local *Agrostis* culture of *P. coronata*; except *A. pilosula*, which is the original host of the test culture, the other two species did not take infection. Further studies on morphological aspects of the pathogen revealed that it is similar to var. *agrostis*, which Peturson (1949) has stated to be similar to var. *agrostidis* (Eriksson, 1897).

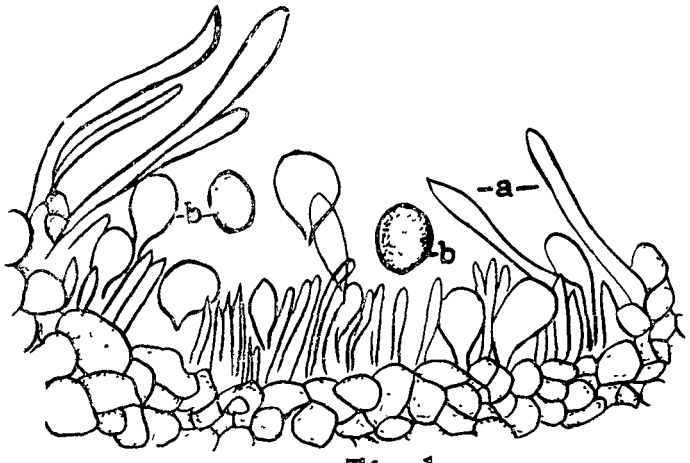

Fig. 1

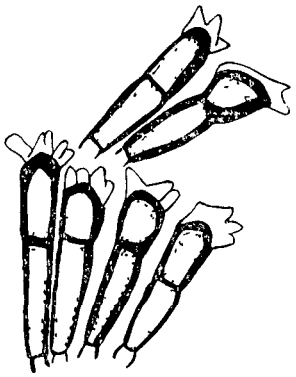

Fig. 2 | 10μ

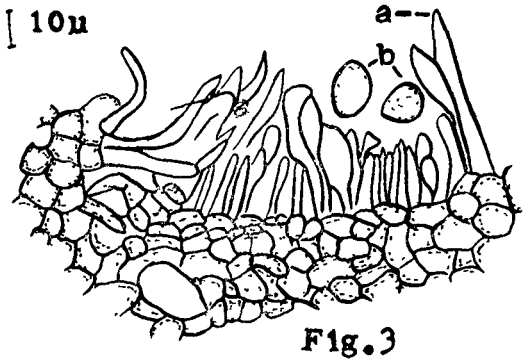

Fig. 3

Fig. 4

FIG. 1. UREDIOSPORES OF *P. coronata* VAR. *festucae*. *a*, Paraphyses; *b*, Urediospores.
FIG. 2. TELIOSPORES OF *P. coronata* VAR. *festucae*.
FIG. 3. UREDIA OF *P. coronata* VAR. *agrostis*. *a*, Paraphyses; *b*, Urediospores.
FIG. 4. TELIOSPORES OF *P. coronata* VAR. *agrostis*.

P. coronata has been reported on *Festuca gigantea* (L.) Vill. (Barclay, 1891), and *F. elatior* L. (Brown, 1937). Barclay (1891) reported the teliospore dimension of the rust to be 43–55 $\mu \times 8$–14 μ. In these studies these were found to be 36–65 $\mu \times 12$–18 μ. Brown (1937) reported that crown rust on *F. elatior* was able to infect *Lolium perenne* L. and *Dactylis glomerata* L. besides other grasses. In the present studies *L. perenne* and several other strains of *D. glomerata* did not take infection. It is therefore concluded that the Simla culture of crown rust may be different from that of Brown (1937). A complete description of the culture on *Festuca* is given in Table II.

SUMMARY

Puccinia coronata var. *agrostis* (Eriksson) Peturson specialized on *Agrostis pilosula* Trin. and *P. coronata* var. *festucae* Fraser & Led. specialized on *Festuca gigantea* (L.) Vill. have been described from India. The two varieties of crown rust have been differentiated morphologically, besides their specialization for pathogenicity on the uredial and telial hosts. *Rhamnus purpureus* Edgw. has been found to be the alternate host for the two forms of the rust.

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EFFECT OF MALEIC HYDRAZIDE ON WHEAT AND BARLEY AGAINST DIFFERENT RUSTS

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Maleic hydrazide has been reported to have various effects in host and parasite relationships. In low concentrations it decreased the resistance of wheat against *Puccinia graminis* Pers. *f. tritici* Erikss, and E. Henn. and *Puccinia recondita* Rob. & Desm. (Samborsky and Shaw, 1957; Samborsky *et al.*, 1960; Joshi, 1966); of barley against *Puccinia hordei* Otth. and *Helminthosporium sativum* Pam., King and Bakke (Joshi, 1965; Richardson, 1957) and of flax against *Fusarium oxysporum* f. *lini* (Bolley) Snyder & Hans; (Nair, 1958). However, the infection of *Puccinia coronata* Cda. var. *avenae* Fraser & Led. on oat and *P. recondita* on wheat was suppressed with maleic hydrazide in high concentrations (Simons, 1955; Samborsky *et al.*, 1960). So far it has not been worked out whether maleic hydrazide has any effect on susceptibility of a host to a pathogen other than its own.

The effect of the reactions of wheat to *P. hordei* Otth., *P. sorghi* Schw. and *P. coronata* Cda. var. *avenae* Fraser & Led. and of barley to *P. graminis* Pers. var. *avenae* Erikss. & E. Henn. and *P. recondita* Rob. & Desm. are reported in the present article.

EXPERIMENTAL

Two sets of barley varieties, viz. ' Egypt 4 ', ' Quinn ', ' Fongtein ', ' E.B. 999 ' and ' Barly Local ' were grown in pots of 10 cm, keeping five seedlings in each. In one set 50 ml per pot, and in the other 70 ml per pot, of solutions of maleic hydrazide at the concentrations of 0·1 per cent, 0·05 per cent and 0·02 per cent were given separately as soil drench. The plants were not watered 24 hours before and after the treatment. The treatment was given at the time of emergence of the leaves and was replicated three times with a suitable control. Young seedlings were inoculated with race 7 of *P. graminis* var. *avenae* and were incubated for 48 hours. These were transferred to glass-house at 20° to 26° C and observations were taken after 16 days of inoculations (Table I).

Maleic hydrazide at the concentration of 0·02 per cent has been more effective in reducing the resistance of ' Egypt 4 ', ' Quinn ', ' E.B. 999 ' and ' Barley Local ' when given at the rate of 70 ml per pot. However, at 50 ml per pot only ' E.B. 999 ' became susceptible. In both the cases ' Fongtein ' did not show any susceptibility to infection.

In the second test ' Agra Local ' wheat and barley were grown in pots of 10 cm. These pots (four of wheat and two of barley) having five seedlings each were supplied

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TABLE I. INFECTION TYPES PRODUCED BY THE BARLEY VARIETIES TREATED WITH MALEIC HYDRAZIDE AGAINST RACE 7 OF *P. GRAMINIS* VAR. *AVENAE*

Varieties	50 ml maleic hydrazide/pot (% concentrations)				70 ml maleic hydrazide/pot (% concentrations)			
	0·1	0·05	0·02	Control	0·01	0·05	0·02	Control
'Egypt 4'	0;	0;	0;–1	0;–1	0;	0;–1	2–3	0;
'Quinn'	0;	0;	0;	0;–1	0;	0;–1	3	0;
'Fongtein'	0;	0;	0;	0	0;	0;–1	1–2	0;
'E.B. 999'	0;	0;	2–3	0	0;–1	0;–1	3–4	0;
'Barley Local'	0;	0;–1	0;–1	0;	0;–1	1–2	3	0;

*Infection types as given by Stakman *et al.* (1962).

with 70-ml solution of maleic hydrazide per pot at the concentration of 0·02 per cent as described above. One set comprising two pots, one of wheat and the other of barley, was inoculated with race H3* of *P. hordei* and the other set was inoculated with race 17* of *P. recondita*, whereas the remaining two pots of local wheat were inoculated with the race 227* of *P. coronata* var. *avenae* and *P. sorghi* separately with some suitable control for each.

The infection types produced by these varieties are recorded in Table II.

TABLE II. INFECTION TYPES* PRODUCED BY RACES OF RUST ON WHEAT AND BARLEY TREATED WITH MALEIC HYDRAZIDE

Pathogens	Maleic hydrazide 70 ml/pot (0·02%)		Control			
	'Wheat Local'	'Barley Local'	'Wheat Local'	'Barley Local'	'Wheat Local'	'Maize Local'
P. recondita (race 17)	4	2–3	3–4	0;–1	—	—
P. sorghi	0;	—	0	—	—	3–4
P. hordei (race H 3)	—	4	—	3–4	—	—
P. coronata var. *avenae* (race 227)	0;	—	0	—	3–4	—

*Infection types as given by Stakman *et al.* (1962).

It is seen from Table II that the application of maleic hydrazide reduces the resistance of 'Barley Local' against *P. recondita*. In both the treated 'Wheat Local' and 'Barley Local' the sporulations of *P. recondita* and *P. hordei*, respectively, were more than on untreated ones. However, maleic hydrazide failed to bring any change in the resistance of 'Wheat Local' against *P. sorghi* and *P. oronata* var. *avenae*.

*Races maintained at the Plant Pathological Substation, Flowerdale, Simla.

DISCUSSION

Maleic hydrazide is known to act as growth-stunting agent (Currier *et al.*, 1951; Waggoner and Dimond, 1952). It was found to reduce considerably the resistance of barley variety against *P. graminis* var. *tritici* and *P. recondita*. Browning (1960) reported similar effect of sucrose solution on wheat and barley against different rusts. However, in the present studies the effect of maleic hydrazide was not found to be the same in all cases. Its effect was also observed to be specific for different varieties of barley as is evident in case of ' Fongtein ', where its effect was found to be negligible as compared to other varieties. Maleic hydrazide at the concentration of 0·1 per cent and above does not have much effect on the pathogenesis of resistant varieties. In the present studies it was found that the effect in relation to pathogenesis was of varying degrees; in some cases it increased the susceptibility of the host, whereas in others such effect was not observed. It is therefore possible that the pathogenesis in comparatively regulated by the amount of nutrient present in the host as a result of the application of maleic hydrazide.

SUMMARY

Maleic hydrazide at the concentration of 0·02 per cent when applied at the rate of 70 ml per pot reduced the resistance of barley varieties, ' Egypt 4 ', ' Quinn ', ' E.B. 999 ' and ' Barley Local ' considerably against *Puccinia graminis* var. *avenae*. It was also found to reduce the resistance of ' Barley Local ' against *P. recondita*. On the other hand, it failed to affect the resistance of ' Wheat Local ' against *P. hordei*, *P. sorghi* and *P. coronata* var. *avenae*.

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PERFORMANCE OF SOME GRASSES AGAINST CEREAL RUSTS

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Role of certain grasses in the perpetuation of cereal rusts has been known for quite some time now. The hills of India are rich in the grass flora some of them are naturalised while the others are introduced ones. Most of the grass flora is harbouring one rust or more but in event of no systematic work done so far on the rusts on grasses in India, it is rather difficult to assign their correct identity. *Puccinia graminis* Pers., *P. glumarum* (Schm.) Erikss. and Henn. and *P striiformis* West. have been reported on several grasses in India (Butler, 1918; Butler and Bisby, 1931; Misra *et al*, 1965) but none of them is connected with the cereal rusts. However, several other grasses have been reported to be susceptible to one or the other cereal rusts and as such may function as collateral or alternative hosts in nature (Mehta, 1940; Prasada, 1948, 1951; Vasudeva et al, 1953 ; Lele and Rao, 1961 ; Joshi and Merchanda, 1963 ; Misra and Lele, 1963).

Since many new races of wheat rusts and many new grasses have been added in our collection, it was considered necessary that as far as possible these grasses should be tested with cereal rusts in order to determine their performance against these rusts. In view of this, the present studies were undertaken and most of the exotic and indegenous grasses were screened against *P. graminis* var. *tritici*, *P. recondita*, *P. striiformis* and *P. graminis* var. *avenae*.

EXPERIMENTS AND RESULTS : Eighty-eight grasses were raised in the glasshouse, some of these viz., *Agropyron elongatum*, *Agrostis royleana*, *Andropogon squarrosus*, *Arthraxon* sp., *Arundinella nervosa*, *Brachypodium sylvaticum*, *Dactylis glomerata*, *Festuca gigantia*, *F. myuros*, *Helictotrichon virescens*, *Lolium perenne*, *L. temulentum*, *Phalaris minor*, *Poa annua*, *P. nemoralis*, *Sporobolus indicus* were collected from Simla hills. Other grasses viz., *Agropyron semicaustatum* E. C. 3299, *A. pectriniformi* E. C. 3000, *A. trichoforum* E.C. 32998, *Agrostis canina* E.C. 28114, *Arrhenatherum elatius* E.C. 17934, E.C. 17935 and E.C. 17936, *Dactylis* sps. E.C. 16125, E.C. 15126, E.C. 16016, and I.W. 1854, *Echinocloa colonum*, *Festuca* sps. E.C. 15123, E.C. 16741, E.C. 16744, E.C. 16745, E.C. 17035, E.C. 17049, E.C. 18329, E.C. 18342, I.W. 1849 and I.W. 1850, *F. arundinaceae* E.C. 28364, *F. pratensis* E.C. 16733, E.C. 17948 and E.C. 28362, *F. rubra* E.C. 31656, *Lolium* sps. E.C. 16005, E.C. 16127, E.C. 16743, E.C. 16746, E.C. 16747, E.C. 16752, E.C. 16754, E.C. 18330, E.C. 18332, and E.C. 20647, *L. hybridum* E.C. 29302, *L. italicum* E.C. 28304, *L. multiflorum* E.C. 28335, *L. rigidum* E.C. 16753 and E.C. 18147, *Phalaris* sps. E.C. 15122, E.C. 15991 and E.C. 16756, *P. arundinacea* E.C. 28103, *P. tubrosa* E.C. 16754, *Phleum* sps. E.C.

16734 E.C. 16738, E.C. 16739 E.C. 16946, E.C. 17947 and E.C. 18333, *Poa pratense*, *P. pratensis* E.C. 21246 and E.C. 21247, P. *trivalis* E.C. 28151 were obtained from Plant Introduction Centre, Simla. The grasses were kept in the glasshouse for a period of one month in order to determine whether these grasses carry any natural infection of the rusts. Twenty four races and biotypes of *P. graminis tritici*, 17 races of *P. recondita*, 10 races of *P. striiformis* and 4 races of *P. graminis avenae* from type culture collection were used in separate mixtures* for inoculation purposes. The experiment was repeated three times.

All the above, grasses were immune to the four rusts used. In addition to the above grasses which were found to get infection are tabulated in table 1.

TABLE 1 : Reactions* of the grasses against *Puccinia graminis tritici*, *P. recondita*, *P. striiformis* and *P. graminis avenae*

Grass cultures	*P. g. tritici*	*P. recondita*	*P. striiformis*	*P. g. avenae*
1. *Avena byzantina*	I	I	I	4
2. *A. elatior* E. C. 18339	0	0	0	3-4
3. *A. fetua*	0	0	0	4
4. *A. glauca*	3-4	0	0	4
5. *A. sativa* E. C. 19177	0	0	0	2-3
6. *A. strigossa*	0	0	0	0;-1
7. *Bromus uniloides*	0	0	0	I
8. *B. catharticus*	0;-1	0;	0	0
9. *B. japonicus*	3-4	3-4	0	3-4
10. *Hordeum murinum* I. W. 1712	2-3	0	0	I
11. *H. irregulare* E. C. 14491	2-3	0	I	I
12. *H. distichon* E. C. 14489	3-4	0	I	I
13. *Muehlenbergia hugelii*	0	0	3-4	3-4
14. *Vulpia myuros*	0;-2	0;-1	0;	3-4

*Reactions as given by Stakman *et al.*, (1962).

NOTE :— Grasses 1-6 and 10-12 were obtained from Plant Introduction Centre Simla and the rest were collected from hills.

It is seen from the table 1 that all the species of *Avena* except *A. strigossa* get the infection with *P. g. avenae*. Besides *A. glauca* gets infection with *P. g. tritici* also. Species of *Hordeum* were found to be susceptible to *P. g. tritici* only. *P. recondita*, *P. g. tritici* and *P g. avenae* could infect *Bromus japonocus; P. striiformis* and *P. g. avenae* were found to infect *Muehlenbergia hugelii. Vulpia myuros* got infection with *P. g. avenae*. However, none of these grasses was found to be susceptible to all the four rusts under test.

DISCUSSION : Vasudeva *et. al* (1953) reported the susceptibility of *Avena fetua* to *P. g. tritici; Bromus catharticus, B. japonicus* to

P.striiformis; *Hordeum distichon* to *P. recondita* and *Phalaris minor* to *P. g. avenae*. However, in the present studies *Avena fetua* showed resistance against *P. g. tritici* and susceptibility against *P. g. avenae*. Species of *Bromus* have been found to be resistant to *P. striiformis; Hordeum distichon* and *Phalaris minor* were resistant to *P. recondita* and *P. g. avenae* respectively. *Avena glauca* was found to be susceptible with *P. g. tritici* and *Phalaris minor, P. canariencis, Agropyron* species sho wed immunity against all the rusts in these studies; however, Lele andRao (1961) reported *Avena glauca* to be immune to *P. g. tritici, Agropyron* species susceptible to wheat rusts and *Phalaris minor* susceptible to *P. g. avenae. Hordeum murinum* has been reported to be susceptible to *P. g. tritici* (Prasada, 1951; Waterhouse, 1921; Vellega, 1947) which was also found to be susceptible in the present studies. Several grasses like *Phalaris minor Bromus catharticus, B. uniloides, Dactylis glomerata, Lolium perenne, L. temulentum* and *L. rigidum* have been reported to get infection with one or the other rusts (Waterhouse, 1929; Marchinonatto, 1931, Unamuno, 1933; Prasada, 1948 and Hingorani, 1945) which were found to be resistant or immune in the present studies. Such descripencies in the results can partly be explained due to the fact that strains of the grasses may be different from those used by the other workers and also that the grasses in nature have got different genotypic composition through hybridization.

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